DOCUMENT RESUME

ED 137 532 08 CE 010 398

TITLE	Occupational Preparation: Inspection and Quality Control. Student's Manual. The Manufacturing Cluster.
INSTITUTION	Fairleigh Dickinson Univ., Rutherford, N.J.; New Jersey State Dept. of Education, Trenton. Div. of Vocational Education.
SPONS AGENCY	Office of Education (DHEW), Washington, D.C.
PUB DATE	75
GRANT	OEG-0-71-4687(357)
NOTE	139p.; For related documents see CE 010 396-399
AVAILABLE FROM	Superintendent of Documents, United States Government Printing Office, Washington, D. C. 20402 (Stock Number 017-080-01655-9)
EDRS PRICE	MF-$0.83 HC-$7.35 Plus Postage.
DESCRIPTORS	Career Education; Curriculum Development; Guidelines; *High School Curriculum; Instructional Materials; *Job Training; Manuals; *Manufacturing Industry; *Quality Control; Secondary Education; *Trade and Industrial Education; Vocational Education

ABSTRACT

This manual is written as a direct followup to the "Exploring Occupation in Manufacturing Student Manual," the purpose of which was to (1) promote an understanding of manufacturing industry; (2) acquaint students with structures of the many careers, occupations, and jobs contained within manufacturing enterprise; (3) explore selected career fields by use of a typical program example, and (4) provide a generalized set of guidelines for further and related curriculum development in the exploration realm. This manual has the same purposes and continues them into the preparation phase by using a program example in curriculum development guidelines. The program guide is designed to fit into the scope of secondary school programs in the academic, industrial, and vocational curricula. Content is presented in two sections, a general overview of quality control and the inspection field and a section on specific occupational preparation. The general overview section (22 pages) contains consideration of major influences and environment encountered within the manufacturing enterprise in the quality control career field; an overview of statistical usage in quality control; and description and prescription of the job and occupational hierarchy contained within the quality control career field. The occupational preparation section (92 pages) provides guidelines for development of curriculum in five major quality control categories found in most industries: Blueprint reading, basic statistics, mechanical measurement, electrical measurement, and chemical measurement. (LAS)

Documents acquired by ERIC include many informal unpublished materials not available from other sources. ERIC makes every effort to obtain the best copy available. Nevertheless, items of marginal reproducibility are often encountered and this affects the quality of the microfiche and hardcopy reproductions ERIC makes available via the ERIC Document Reproduction Service (EDRS). EDRS is not responsible for the quality of the original document. Reproductions supplied by EDRS are the best that can be made from the original.

ED137532

THE MANUFACTURING CLUSTER

OCCUPATIONAL PREPARATION—

INSPECTION AND

QUALITY CONTROL

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

STUDENT'S MANUAL

2

CE 010 398

Developed pursuant to Grant No. OEG-0-71-4687(357)
by the New Jersey State Department of Education,
Division of Vocational Education

A project funded by the United States Office of Education
under Part I - Curriculum Development in Vocational and
Technical Education, Vocational Education Amendments of 1968,
Public Law 90-576
1975

This document is part of the Manufacturing Cluster Series which addresses itself to career awareness, orientation, exploration and preparation.

The series includes student manuals and instructor guides for use at the secondary level.

The list of titles in this series is as follows:

Exploring Manufacturing Occupations: Student's Manual

Exploring Manufacturing Occupations: Instructor's Guide

Occupational Preparation - Inspection and Quality Control: Student's Manual

Occupational Preparation - Inspection and Quality Control: Instructor's Guide

For sale by the Superintendent of Documents, United States
Government Printing Office, Washington, D.C. 20402.

STOCK NO. 017-080-01655-9

FOREWORD

This Occupational Preparation in the Quality Control and Inspection Field Student Manual is written as a direct follow-up of the Exploring Occupations in Manufacturing Student Manual. The Exploring Manual's purpose was to:

1. promote an understanding of manufacturing industry;
2. acquaint the students with structures of the many careers, occupations and jobs contained with manufacturing enterprise;
3. explore selected career fields by use of a typical program example; and
4. provide a generalized set of guidelines for further and related curriculum development in the exploration realm.

This Manual continues those four purposes into the preparation phase in the same manner. This is accomplished by utilizing a program example in the curriculum development guidelines.

As was the case in the exploration phase, some delimitation in the preparation for career fields was necessary. The concentration in quality control was chosen because it contains skills and knowledge that are broad; the comprehensive job classes examined have high relationship with all of the major sub-functions of manufacturing enterprise. This program guide will fit within the scope of purpose and present on-going secondary school programs in the academic, industrial and vocational curriculums.

The teaching/learning program team model contained in the exploration phase is suggested as a resource in the curriculum developed as a result of this Manual. The conduct of the program--as specific skills are developed becomes the focal point--encouraging use of prescribed resources.

The Manual is presented in two sections, a general overview of quality control and the inspection field and specific occupational preparation.

The general overview section contains consideration of major influences and environments encountered within the manufacturing enterprise in the quality control career field; an overview of statistics usage in quality control; and description and prescription of the hierarchy of jobs and occupations contained within the quality control career field.

The occupational preparation section provides guidelines for development of curriculum in five major quality control categories found in nearly all industries, namely: Blueprint Reading; Basic Statistics; Mechanical Measurement; Electrical Measurement; and, Chemical Measurement.

By approaching the preparation phase in a broad sense, it is hoped that interested students will see the importance of their skills and knowledge in quality control and inspection across the industrial job market. Also, for those students interested in higher echelon careers in quality control, the basic preparation can allow them the same broad view of a field rather than one job.

It is sincerely hoped that this Manual serves those purposes.

John E. Radvany
Deputy Assistant Commissioner
New Jersey Department of Education
Division of Vocational Education

ACKNOWLEDGEMENTS

As with any project encompassing such a diversified field as Manufacturing Enterprises, this is the result of the efforts of countless persons who have supplies the knowledge, and the facts upon which it rests. Philosophy, rationale, information, critique, testing and change have been reviewed by special personnel who worked on, or supplied information to this project.

To all the many advisory personnel and committee members, sincere thanks are due. It is impossible to list them all and delineate their contribution.

The Manufacturing Cluster Series of which this is a part represents an effort in curriculum development by the United States Office of Education, the New Jersey Department of Education and Fairleigh Dickinson University.

TABLE OF CONTENTS

Page

FOREWARD iii

ACKNOWLEDGEMENTS.. v

OCCUPATIONAL PREPARATION IN THE QUALITY CONTROL AND INSPECTION FIELD

INTRODUCTION.. 1
SYSTEMS TECHNOLOGY AND QUALITY CONTROL............................ 2
STATISTICS IN QUALITY CONTROL..................................... 7
OVERVIEW OF INSPECTION AND MEASUREMENT........................... 15
THE QUALITY CONTROL CAREER FIELD................................. 22

SPECIFIC OCCUPATIONAL PREPARATION SUBJECT MATTER

INTRODUCTION... 26
BLUEPRINT READING.. 26
MECHANICAL MEASUREMENT... 53
OPTICAL AND ANGULAR MEASUREMENT.................................. 99
ELECTRICAL MEASUREMENT.. 102
CHEMICAL MEASUREMENT.. 118

Occupational Preparation in the Quality Control and Inspection Field

INTRODUCTION

Students who have selected preparation in this career, occupation or job field should have had some prerequisite instruction in the manufacturing enterprise area. Typical pre-preparation would include:

1. Instruction and experience gained in the Exploring Manufacturing Occupations Program from the Manufacturing Cluster Series; and/or,
2. Instruction and experience gained in The World of Manufacturing Program; McKnight and McKnight, Bloomington, Illinois. 1971; and/or,
3. Instruction and experience gained in an industrial arts or vocational program or selected skills acquisition courses in trade or general laboratory; general physics and chemistry; economics and basic math.

There is no specific determinable degree of skills and knowledge needed in any of the above areas in order to participate in the following program but a high interest in these areas would be a great aid. The first section of this manual synthesizes and articulates, in a general overview, selected major influences and related quality control and inspection knowledge areas contained within manufacturing. These syntheses, generally, encompass areas of history, economics, systems technology and career development.

The second section contains a guideline for specific skills and knowledge acquisition in the areas of: Blueprint Reading; Basic Statistics; Mechanical Measurement; Electrical Measurement; and Chemical Measurement.

An important factor in the preparation phase is the necessary overlap in related education and training between that which is called exploration and preparation. There is no definite cleavage between the two phases. Exploration continues along with preparation. Students may drop out during the preparation program due to many reasons. One reason could be a near the end of the program decision not to pursue this type course of instruction, even though the student developed competency in the course.

In this case, students may still be exploring, i.e., changing their direction and/or focus due to awareness of other and more interesting career areas they would like to explore for career preparation. This can be accomplished in this particular course of instruction. Inspection skills are important to the quality control concept in this career. After exploring and trying the inspection field, students may select the higher technician or engineering echelons of the career field. This may require the students and school system to rearrange their programs with a balance of academic and vocational subjects, possibly with an emphasis on academic subjects.

It is the concept of career education to promote studies with students involvement in awareness, exploration and preparation phases so that they can realize their potential. Usually, potential is expressed upwards and towards the top. Course emphasis and specific design to the lowest point will not serve the goal of education or the student.

The career education concept emphasis is on promoting student potential in work-related dimensions. This course of instruction should not be interpreted as a method of helping students to become inspectors or even quality control engineers. This is a course designed to help and encourage students to prepare themselves along educational and training lines in a wide selection of career choices. This type experience and instruction has, as its main purpose, the objective of supplying information to promote understanding of this career field. When this objective is met, additional activities of narrower field selection, intensive occupational or job preparation and/or recognition and planning for advanced formal education can be better accomplished.

SYSTEMS TECHNOLOGY AND QUALITY CONTROL

BACKGROUND INFORMATION

Systems technology is the knowledge we have collected about systems, their performance and their characteristics. For a system to exist, it must have a purpose, a mission, or a task that it can perform.

The American Society for Quality Control defines a system as:

> "A group of interacting human and/or machine elements, directed by information, which operate on and/or direct material, information, energy, and/or humans to achieve a common specific purpose."

Listed below for student consideration are typical systems for quality control such as:

Solar system
Stellar system
Economic systems
Political systems
Transportation systems
Communication systems
Educational systems
Distribution systems
Aerospace systems
Quality Control systems

The reasons for stressing the system concept to interested students are aptly presented in A. V. Feigenbaum's article, Major New Developments in Systems Engineering. He states that engineered systems are better for the following reasons:

1. They operate at optimum speed and with optimum response.
2. There is harmony among its human elements.
3. They integrate human and machine elements.
4. They provide higher output/input productivity.
5. They provide output optimization.
6. They provide economy of operation.
7. They allow overall control of action.
8. They influence higher reliability.
9. They provide for effective maintainability.

A manufacturing system consists of eight major stages as described by A. V. Feigenbaum. They are:

Marketing
Engineering
Purchasing
Manufacturing Engineering
Shipping
Manufacturing Supervision and Shop Operations
Mechanical Inspection and Functional Test
Installation and Service

Quality systems also provide the benefits to manufacturing industries as they were listed above. The elements of these systems include:

People
Equipment
Information

QUALITY CONTROL SYSTEMS

In the field of quality control, which is in itself a system, there are specific definitions also. One of these definitions listed by A. V. Feigenbaum in Total Quality Control, states:

> "The quality system is the network of administrative and technical procedures required to produce and deliver a product of specified quality standards."

The key elements of a quality system as described by A. V. Feigenbaum are as follows:

1. Production Quality Evaluation - The establishment of procedures to analyze formally both the product design and the process design to ascertain that the resultant product will fulfill the customer's requirements.

2. Product and Process Quality Planning - The formalizing of plans to measure, attain, and control the desired product quality.

3. Purchased Material Quality Planning, Evaluation, and Control - Provides the procedures necessary to control purchased material.

4. Product and Process Quality Evaluation and Control - The procedures established for implementing the product and process quality planning.

5. Quality Information Feedback - The information system which forms a part of the quality system.

6. Quality Information Equipment - The equipment that provides the quality measurements that are necessary for the control of quality identified during product and process quality planning.

7. Quality Training, Orientation, and Manpower Development - Provides the means for developing the people capability required to properly operate the quality system.

8. Postproduction Quality Service - The service provided to ensure the consumer a product will function as expected.

9. Management of the Quality Control Function - The procedures the manager uses in getting his job of managing done.

10. Special Quality Studies - Provides procedures and techniques for identifying specific quality problems and finding specific solutions for such problems.

The quality system provides the channels through which the stream of product-quality-related activities flow. This, together with other systems, makes up the main line flow of the total business system.

THE MANUFACTURING PROCESS AS A SYSTEM

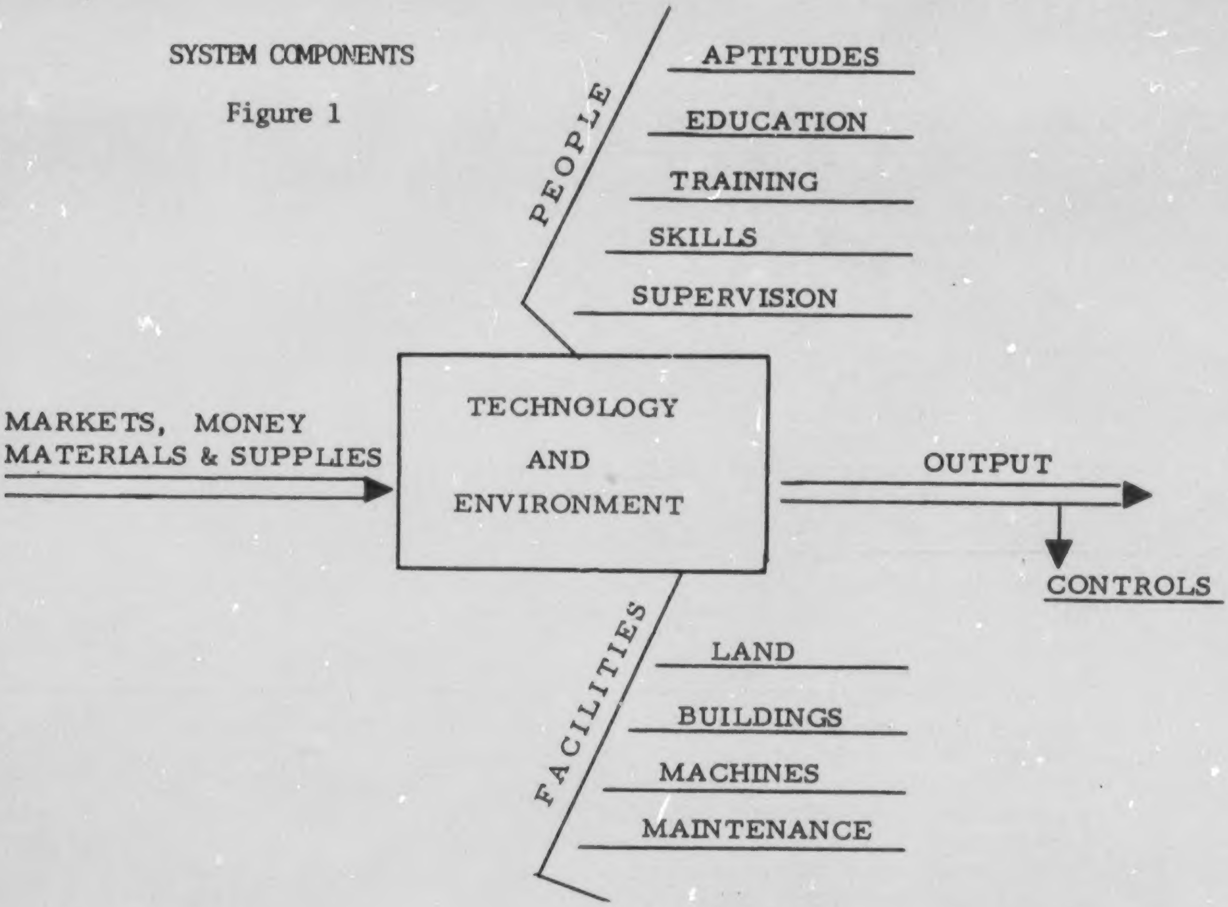
Applying the eight stages of a manufacturing system into an operational function requires an understanding of the fundamental factors that affect quality. These seven basic factors are:

Markets	Management
People	Materials
Money	Machines and Methods

These factors must be considered in the manufacturing process at all times. The following diagram shows the general construction of a model for a manufacturing system.

SYSTEM COMPONENTS

Figure 1



Additional explanation of terms for the manufacturing system model in Figure 1 on page 5 are:

1. Technology - Includes the selection of the product to be manufactured and the process by which it is produced.

2. Resources - Include the materials and parts used to make the products and the power and fuel required to operate the production machines.

3. Facilities - Include the machines and equipment used to produce the product.

4. Buildings - To house the people and equipment.

5. Maintenance - Keep the facilities operating and in good condition.

6. Labor - The people who operate the machinery and run the factory. They require: Aptitudes; Education and Training; and Skills.

ROLE OF INSPECTION IN QUALITY CONTROL

The quality of a product is directly related to the reputation and success of a company. The better its product, the better its reputation and the better its sales will be. When the product is designed, the engineering department establishes the specifications and, therefore, a standard of quality. The shops make or fabricate the product according to drawings and specifications. It is the function of the inspection division to ensure that the quality of the finished product is in accordance with standards that are established.

Inspection does not create quality, but it does help to control quality. It provides the means of measuring the quality of materials and workmanship which enter into the product. This does not mean the production workers do not have a responsibility when completing a task since they have to measure or otherwise examine their work at various steps in the process.

There is more to inspection than merely checking the quality level of the finished product. The aim is to prevent defects by discovering and eliminating the causes of the problem. By early detection of a slight variance, the correction of a difficulty may take place by a minor machine adjustment. If inspection was not available, many below-standard parts could be produced. This would result in a loss of parts and a loss in time because a complete new set-up of the machine would have to take place. Early inspection can detect conditions which could lower the quality of the product.

STATISTICS IN QUALITY CONTROL

THE NEED FOR STATISTICS

One of the most important tools used by the quality control specialist is the mathematics of statistics and probability. Statistics is a technical word for the study of the results of such actions as tossing a coin, throwing a pair of dice or playing a card game. The concept of "playing the odds" has fascinated humans since the beginning of time. But the practical use of statistics is a relatively recent development, with its primary growth during the Twentieth Century. Statistics are used in medicine, education, research, business and economics.

The principal value of statistics is its application to the examination and review of information obtained from a small sample. The information obtained from this sample can be a very accurate measurement for the entire population or group from which the sample was taken. The use of polling techniques to predict elections and the use of computers to predict the outcome on election night are examples of statistical applications. Television programs are rated based on a statistical sampling of about 1,000 families randomly selected throughout the United States (Nielsen Ratings). From this sample of families and some supplemental telephone surveys, the analysts are able to estimate the television viewing habits of all the families in the United States.

When referring to quality control by statistical methods, it is meant specifically to those quality control techniques which involve the use of statistical data. The term "statistics" has caused a great deal of consternation in industry since it is generally associated with highly involved theories and mathematics. However, the student should realize that statistical methods in industrial daily use have been reduced to very elementary arithmetic and may be substantiated by simple logical deduction.

There are three basic areas of concentration to which statistical quality control techniques are generally applied. They are:

1. Process controls
2. Acceptance techniques
3. Special job studies

1. Process Control

As material is processed, samples are taken and inspected. Based upon the results of these inspections, the process is either judged to be operating in a normal fashion or subject to unusual conditions. This decision is based upon the interpretation of a quality control chart. The control charts may be divided into two categories--those for variable and those for attribute data.

Whenever the inspections involve a numerical classification of a quality characteristic, the data is said to involve variables. When a diameter is recorded in inches, hardness in Rockwell units, chemical contents in precentages, or an angle in degrees, the data are recorded as a variable. If a part is simply judged good or bad, the data is recorded in terms of attributes. The material either is the proper hardness or it is not, the chemical content is either acceptable or it is not, the weld either exists or it does not, the finish is either smooth enough or it is too rough. These classifications provide data in attribute form.

a. X-R Charts

These charts are for variable data.

b. p, np, and c Charts

These charts are for attribute data.

Quality control charts provide their greatest benefit by detecting, at the earliest possible time, conditions which cause defective material. Thus, a process may be corrected before it produces large quantities of borderline or defective material.

2. Acceptance Sampling

Acceptance sampling techniques are designed to permit valid decisions on material to be based upon a relatively small sample. This allows inspection of a sample of the parts and a possibility to decide upon this evidence whether or not the entire group of parts is satisfactory. Most of the acceptance sampling plans are based upon attribute inspection. The sampling plans which are gaining the widest acceptance are the Military Standard Sampling Procedures and Tables for Inspection by Attributes, or MIL-STD-105D, the international designation of which is ABC-STD-105.

3. Special Job Studies

Very often certain quality information is desired which is not available from the control charts and acceptance techniques in use. Special statistical techniques may be used to analyze the data collected. This may involve special applications of the control chart techniques or may involve other more advanced statistical techniques. Some of the more common studies might involve the determination of process capabilities, the review of existing specifications, the investigation of the relationship of various chemical or physical properties of a material to some formed dimension, and the comparison of certain alternate processes.

Benefits that are obtained from statistical quality control are listed as follows:

1. Prevents unnecessary inspections.
2. Provides facts for decision making.
3. Improves inspection methods.
4. Improves flow of material.
5. Stimulates quality consciousness.
6. Influences vendor goodwill.
7. Improves product quality.
8. Allows process capabilities information.
9. Reduces scrap.

BASIC STATISTICAL METHODS

For the entry level student into the manufacturing industry, only a few of the basic statistical methods should be necessary. These mathematical tools are:

Average:	A measure of central tendency. It is the arithmetic mean of the observed values.
Range:	A measure of variation. It measures the spread of the distribution.
Distribution:	Observed values will be distributed about an average. There are approximately the same number of values above and below averages. Some of the common distribution curves used in industry are: 1. Normal - balanced distribution with the highest number of readings at the average point. 2. Poisson 3. Students "t" 4. Chi square

	5. Exponential 6. Rectangular 7. Bathtub
Standard Deviation:	A measure of dispersion of a normal distribution.
Control Charts:	Charts used to plot inspection data collected from the manufacturing process being monitored. This type of chart is the most widely used in industry for variable data collection. Some practical applications are: 1. Temperatures of iron, furnaces, air. 2. Strength tests on products. 3. Volumes of containers 4. Weights of packaged goods. 5. Moisture contents of lumber. 6. Sizes of formed dimensions. 7. Chemical analyses of materials. 8. Finishes of metals or glasses.
Sampling:	When a random selection of parts are made from a group or lot of parts and inspections are made on these few to determine acceptance or rejection of the entire lot.
Frequency Distribution:	A tabulation of distribution data shown in graphical form such as the normal curve or a histogram.

THE USE OF STATISTICS IN INDUSTRY

The departments in manufacturing companies concerned with the statistical data forms mentioned above, especially the control chart, are:

Inspection or Quality Control - Collects the data, tabulates and charts the information, analyzes the data, and makes the interpretations concerning the conformance.

Production Department - Responsible for the adjustment and repair of the process and the supervision of the operators who actually control or operate the production equipment. It is responsible for the quality of the product.

Methods Department - Responsible for providing adequate tools, fixtures, etc. It is involved in decisions regarding machine repairs which are realized through control chart studies.

Design - Study the process capabilities relative to necessary specification tolerances that could result in a change of specification.

Other Departments - Almost all departments associated with manufacturing and service will at one time or another, take action which has been directed from the findings of the control chart. Machine replacements, material changes, and personnel changes are all possible results of quality control investigations.

The industrial use of statistical data by the departments listed above is made necessary because of production variations. Variations are differences in the results of subsequent samples and are the results of the following:

1. Variations due to sampling fluctuation.
2. Variations due to process change.
3. Variations due to faulty inspection techniques.

It is because of these variations that the manufacturing industry needs trained quality control personnel and emphasize adequate training of the entry level high school student.

EDUCATION, TRAINING, AND PROFESSIONAL DEVELOPMENT IN QUALITY CONTROL

There are many opportunities and challenges in the field of manufacturing quality control for the graduating high school student. Since the proper performance of all manufactured products depends on quality, the modern quality professional should be aware of the opportunities that enhance personal, company, and community growth and development.

The quality control field provides the following employment opportunities to the inquiring student:

- Inspection
- Technical Development
- Quality Engineering
- Reliability Engineering
- Quality or Reliability Management

The high school student preparatory requirements that are considered basic for the entry into the manufacturing industry are first presented and then followed with an approach to continued professional development.

HIGH SCHOOL PREPARATORY CURRICULUM

For the high school student to be prepared to enter the world of work in the quality control field, basic educational development would be beneficial. The following is recommended for the student interested in this field:

Prerequisites		Concentrations
Basic Mathematics	Human Relations	Electronics in Quality Control
Algebra	Quality Control Concepts	Nondestructive Testing
Trigonometry	Mechanical Measurements	Process Control
Geometry	Blueprint Reading	Metallurgy
Drafting	Statistics	Reliability Concepts
	Quality Reports/Data	Quality Costs
	Specification Preparation	

ON-THE-JOB TRAINING

On-the-job training is the most common of all training methods for inexperienced quality control employees. The amount of training necessary will depend on the industry and the complexity of the product being manufactured. Since the majority of companies do not have formal training programs, they rely on the high schools to prepare the student in basic educational needs. Specific skills are then learned by the new employee on an "as-required" basis.

Many of the skills are specialized and require a long training period and even certification in some situations. It, therefore, is necessary for the student to learn as many of the prerequisites as possible before entering the world-of-work in the manufacturing industry.

APPRENTICESHIPS

Certain manufacturing companies have apprenticeship programs in the field of quality control. These opportunities are very limited and do require a minimum of four years training and education. It does provide the company with a well trained employee but it is expensive to monitor and coordinate.

A high school diploma is required and a good background in science, mathematics, and shop practices is desirable for all trades. The apprentice then may earn up to forty (40) units of college credit for on-the-job training and related technical instruction. Then with an additional twenty (20) units of college credit, the student may qualify for an Associate of Science Degree in a junior college where this program exists.

COLLEGE TRAINING

To help the student understand the educational opportunities that are available in American colleges and universities, the following is a list of certificates and degrees offered in the field of quality control:

Proficiency	Approximate Credit Requirements
Certificate of Proficiency	27 Semester Units
Associate Degree	60 Semester Units
Bachelors Degree	124 Semester Units
Master's Degree	154 Semester Units

Many colleges in this country now have some type of quality control course offering available to the student seeking continued education. An example of a career ladder available to a student in the quality control profession is illustrated in the following matrix entitled, "Educational Matrix Ladder for Quality Control," (See Figure 2, Page 14).

PROFESSIONAL CERTIFICATIONS

The American Society for Quality Control is the major professional society related to the field of quality control. Just as many professional organizations do, this society offers membership at various levels of a career. There is a student membership available for the high school student at a very nominal cost.

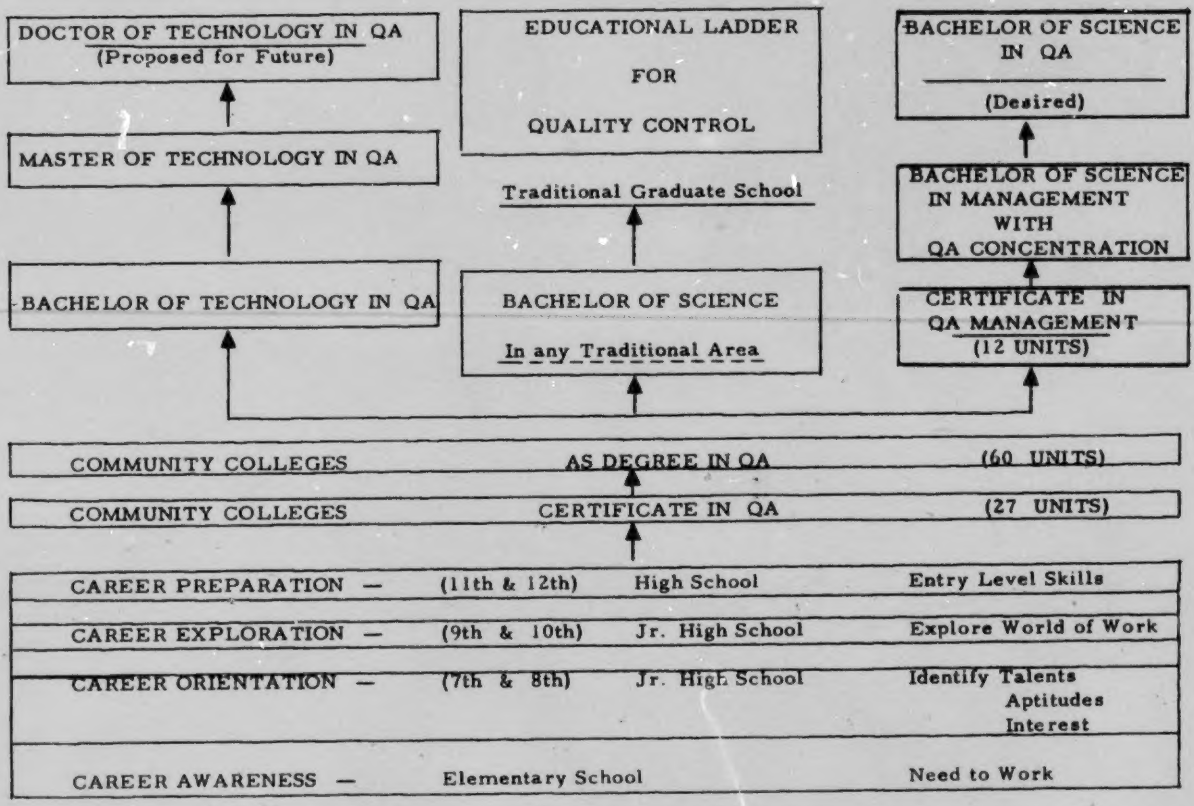
Of major significance, however, the American Society for Quality Control recognizes professionalism through the media of certification. The inspector that is aspiring for a career in this profession may prepare to become a Certified Quality Technician. Currently, there are several specific options that are available in this certification area. They are:

- Chemical
- Food and Allied Industries
- Electronics Inspection
- Electronics Technician
- Mechanical Inspection
- Nondestructive Testing
- Inspection (Proposed)
- Nuclear Power (Proposed)

Certification is a recognition of professional peers that an individual who, "in support of and under the direction of professional engineers, certified quality or reliability engineers, quality managers or scientists can carry out in a responsible manner, proven quality techniques or those techniques prescribed by engineers."

EDUCATIONAL MATRIX LADDER FOR QUALITY CONTROL EDUCATION

Figure 2


DOCTOR OF TECHNOLOGY IN QA
(Proposed for Future)
MASTER OF TECHNOLOGY IN QA
BACHELOR OF TECHNOLOGY IN QA
EDUCATIONAL LADDER FOR QUALITY CONTROL
Traditional Graduate School
BACHELOR OF SCIENCE In any Traditional Area
BACHELOR OF SCIENCE IN QA
(Desired)
BACHELOR OF SCIENCE IN MANAGEMENT WITH QA CONCENTRATION
CERTIFICATE IN QA MANAGEMENT (12 UNITS)
COMMUNITY COLLEGES AS DEGREE IN QA (60 UNITS)
COMMUNITY COLLEGES CERTIFICATE IN QA (27 UNITS)
CAREER PREPARATION — (11th & 12th) High School Entry Level Skills
CAREER EXPLORATION — (9th & 10th) Jr. High School Explore World of Work
CAREER ORIENTATION — (7th & 8th) Jr. High School Identify Talents Aptitudes Interest
CAREER AWARENESS — Elementary School Need to Work

(NOTE: Based on programs in San Diego, California - 1974)

OVERVIEW OF INSPECTION AND MEASUREMENT

There are many different aspects of quality control in manufacturing that require basic skills relative to various inspection techniques. This section will explore the different inspection types and the respective tools used in industrial measurement.

TYPES OF INSPECTION

There are a wide range of inspection classifications in industry. Some of the general types are:

1. Source Inspection - The inspection of hardware at the source of production. Usually occurs when the purchaser does not have the adequate testing and/or inspection facilities.

2. Incoming Material Inspection (Receiving Inspection) - Inspections performed at the purchaser's plant to determine if material conforms to purchase order requirements.

3. Normal Inspection - When there is no significant evidence that the quality of product being submitted is better than or worse than specified requirements.

4. In-Process Inspection - Inspection which is performed during the manufacturing or repair cycle in the effort to prevent defectives from occurring and to inspect the characteristics and attributes which are not capable of being inspected at final inspection.

5. First Article Inspection - Complete inspection of the first article produced or received.

6. Qualification Inspection - Examination and testing as required in an individual specification to determine whether a product is satisfactory for listing on a qualified producers list.

7. Inspection by Attributes - Inspection wherein the unit of product is classified as defective or nondefective with respect to a given requirement or set of requirements.

8. Inspection by Variables - Inspection wherein a specified quality characteristic in a unit of product is measured on a continuous scale.

Other important inspection factors are:

1. Inspection Level - Used to indicate the relative number of sample units for a given amount of product. All other things being equal, a higher inspection level entails a lower risk of acceptance of a lot of inferior quality.

2. Inspection Cot - A collection of units of product from which a sample is drawn and inspected to determine compliance with the acceptability criteria.

3. Inspection Status - A classification of an item as being inspected, withheld, rejected, or accepted with limitations (conditional).

4. Inspection Tests - Demonstrate that an article conforms to the established requirements with respect to function, workmanship, and materials. The basis of acceptance of production articles is controlled with the following tests:

   Quality verification
   Individual acceptance
   Receiving inspection
   Calibration
   Production inspection

5. Inspection Record - Recorded data concerning the results of the inspection with appropriate identifying information as to the characteristic or class of characteristics inspected.

SPECIFICATIONS

The manufacturing industry operates to various specifications while producing their products. These specifications are essential to ensure the quality of the hardware produced and, therefore, the new employee must have an understanding of these requirements. For this reason, basic blueprint reading and specification preparation were considered to be important enough for incorporation to high school curricula.

Some of the basic methods of communicating specifications in manufacturing are:

Blueprints
Operating procedures
Company policies
Rejection documents
Test procedures
Equipment operating procedures
Instruction manuals
Shop planning

The entry level student would receive on-the-job training relative to interpretation and implementing the various specifications listed in the respective place of employment. However, at this level the student should at least be aware of the blueprint basic terminology. These are listed below as a reference to follow for the interested student:

1. Dimensions and Tolerances

    Interpretation of limits
    Datums
    Tolerance of buildup

2. Position Tolerancing

    Coordinate tolerancing
    Polar coordinates
    True position tolerancing
    Symbols
    Concentricity
    Symmetry

3. Form Tolerancing

    Straightness
    Flatness
    Cylindricity
    Profile
    Angularity
    Parallelism
    Perpendicularity
    Runout

4. Surface Texture

MECHANICAL INSPECTION AND MEASUREMENT

The basic mechanical measurements used in manufacturing are based on the following elementary relations:

Precision - exactness, degree of exactitude.

Accuracy - desirability (relation between observed and true values).

Reliability - probability of achieving desired results.

Discrimination - the degree to which an instrument subdivides the unit length (smallest readable).

To delineate the differences between these measurement terms, a variety of mechanical tools are used. Some of the basic units are listed to acquaint the student with these tools.

1. Scales

   Architects and Engineers.

   Combination Square - A blade and a square head (right angle references).

   Protractor Head - For checking angles.

   Combination Set - A combination square with a protractor and center heads.

2. Gauges

   Depth - Measures holes, grooves, recesses.

   Calipers - Instruments that physically duplicate the separation between the reference point and measured point of any dimension within this range.

   Dividers - For line measure; outside calipers, for end measurement; inside calipers, for end measurement; hermaphrodite, for line to end measurement.

   Surface - To transfer height measurements part to standard.

   Micrometer - Measurements of very high amplification by the use of screw threads.

   Gauge Blocks - End standards that combine arithmetically to form length combinations (the basic tool of precision measurement).

   Optic - Optical comparator; microscope, tool makers and electron; x-ray and television.

   Limit - Gauges that measure one single dimension (go/no-go).

   Plug - Hole inspections.

   Ring - Diameters, thicknesses and lengths.

   Snap - Fixed or adjustable calipers used for the size control of external dimensions.

   Taper - Parallels.

   Feeler - Gaps or spaces.

Radius - Center point to arc on circle.

Screw Thread Gauges - For screw thread measurement tolerances.

3. Torque Wrenches - Use to measure the resistance to turning.

4. Surface Plates - Serve as horizontal reference planes of sufficient strength and rigidity that measurement operations may be supported on it. Also used as grinding tables, planning tables, and lathe ways.

5. Surface Roughness Scales - Used for evaluating roughness by sight or fingertip by using a scale with samples of comparable pattern.

6. Protractors, Squares, Levels, Clinometers - Used to measure angles.

ELECTRICAL TEST AND MEASUREMENT

Electrical measurement is one of the major measurement categories of concern to inspection and quality control. The student should be aware of this category of measurement and the basic instruments used by inspectors.

1. Resistance measurement - (common equipment used).

   Ohmmeter
   Voltmeter - Ammeter
   Wheatstone
   Kelvin
   Megohmmeter

2. Current measurement

   Galvonometer - (For small currents in bridge circuits, potentiometers, and other measuring equipment).

   Ammeter (Shunts) - (For larger current measurements).

3. Voltage measurement

   Voltmeter - Measures various ranges of voltage.

   Electrodynamometer - (Uses an air-core electromagnet in lieu of a permanent magnet).

4. Power measurement

   Wattmeter - Measures electric power by employing two elements, one current operated and one voltage-operated.

5. Multiple measurement

Oscilloscope - Permits determination of current, voltage, and frequency by visual graphical relationships.

6. Capacitance and inductance measurement

Schering Bridge
Maxwell Bridge
Hay Bridge
Owen Bridge
Resonance Bridge
Capacitance Comparison Bridge
Inductance Comparison Bridge

MEASUREMENT OF PHYSICAL AND CHEMICAL PROPERTIES

The measurement of special properties of materials, parts, and liquid is often required in manufacturing. Chemical solutions must be tested for the correct mixture. Water must be tested for purity. The weight of parts and products is also important, since many products are priced by the pound or gram. Most physical and chemical properties are too complex to measure by simple experiments. The following are only examples of the kind of measurements required.

Measurement Of Physical Characteristics

Correct determination of weights of objects has significant applications in all fields of American life and occupations.

There are two basic systems of weights and measurements used.

1. British System
    a. The units of weight commonly used in the United States and other English speaking nations were derived from British units in colonial days.
    b. The basic units of weight are: ounces (oz.), pounds (1 lb. - 16 oz.), tons (2,000 lbs.)
2. Metric System
    a. The metric system is ordinarily used for scientific measurement throughout the world and for commercial purposes in most nations.
    b. The basic units of weight are: grams (g), kilograms (kg. = 1,000 grams).

Weights of objects are determined by two basic types of balances.

1. The equal arm balance - This type of balance is by far the most accurate and different variations are found in all laboratories. This type of balance uses the lever principle.
2. Spring balances - These types of balances use a spring mechanism which is compressed when a weight is placed upon them. A direct reading of the compression of the spring records the weight of an object. Since springs lose their elasticity over a period of time, these types of balances are not very accurate.

Chemical Measurements

Qualitative measurement or analysis is used to test for the presence of a certain substance in a sample of material or liquid. They are usually observed by one or more of the senses - taste, odor, touch, and sight.

1. ph measurement - The ph of water is a measurement which determines whether water is acidic, basic (alkaline) or neutral. This is of extreme importance to the sanitary engineer in terms of water softening, proper bacteria action on sewage, corrosive action of water and proper appearance and taste. Depending upon the environment, natural waters can become basic or acidic. Listed below are some common bases and acids found in the home.
    a. Bases - Basic substances have a bitter taste, feel slippery to the touch and turn red litmus paper blue. Some common bases are: ammonia, bleach, baking soda, and lye.
    b. Acids - Acidic substances have a sour taste and turn litmus paper red. Some common acids are: boric acid, lemon juice (citric acid), and vinegar (acetic acid).
2. Flame test of elements - Some chemicals, when placed in the flame of a bunsen burner will give off a color that is characteristic of that element. Some examples of this chemical reaction are as follows:

Substance	Color	Color Due to
NaCl Sodium Chloride	yellow	Sodium
CuNO3 Copper Nitrate	blue-green	Copper
CuCl Copper Chloride	blue-green	Copper
$CaCl_2$ Calcium Chloride	red	Calcium
KCl Potassium Chloride	violet	Potassium
KNO_3 Potassium Nitrate	violet	Potassium

3. Spectral Analysis - A spectroscope is an optical instrument which breaks down the light entering it into separate frequencies by use of a prism or a diffraction grating.

Quantitative analysis is the determination of the presence of a substance in a sample of matter by weight or volume. Quite often the chemistry and mathematics involved in solving quantitative problems require a complete course in chemistry and a good knowledge of mathematics. There are, however, efficient methods employed using standard solutions which make this task simpler. As indicated before, color indicators will determine the presence of a certain substance in a sample of matter. However, if a known amount of the indicator is added to a known volume of the sample, a direct reading of the intensity of the color will indicate the amount of substance present in the sample, as in the:

Determination of chlorine quantity in a swimming pool.
Determination of the ph value of water.

These tests are but two of many color indicator tests that can be done to determine the quantity of any substance in a sample of solution. Modern laboratories will have in stock these standard solutions, which enables the laboratory technician to efficiently and accurately determine the amount of unknown in any sample solution.

THE QUALITY CONTROL CAREER FIELD

A student considering a career in the areas of quality control, inspection and test occupations can see the general structure of the quality control career field in Figure 3, page 24.

For purposes of preparation in the quality control, inspection and test career fields at the secondary level, the area of inspection and test is emphasized primarily. A student contemplating immediate job-entry will, probably, enter at the level of inspector. The immediate job-entry positions are, typically:

Inspector-Trainee - To perform semi-repetitive checking, comparing or inspection functions, including the operation of certain testing machines or equipment, while working under the guidance of more experienced inspectors.

Quality Technician - To perform standard laboratory tests, and preparation and analysis of in-process samples in accordance with established methods and general instructions utilizing appropriate equipment to determine product acceptability.

Inspector - To inspect the fabrication, assembly, mating, functional test and checkout of manufactured products.

Tool and Gauge Inspector - To perform a variety of complicated inspections on all types of first-run precision machined parts to prove accuracy of machine tools. Use complicated inspection and precision measuring instruments and equipment. Inspect, maintain, adjust, and order all thread and plug gauges used in a company operation.

Assembly Inspector - Inspect electrical and mechanical assemblies and subassemblies.

Shipping Inspector - Inspect components, parts, assemblies, spares, tools, associated ground support and test equipment, raw materials for shipping preparation.

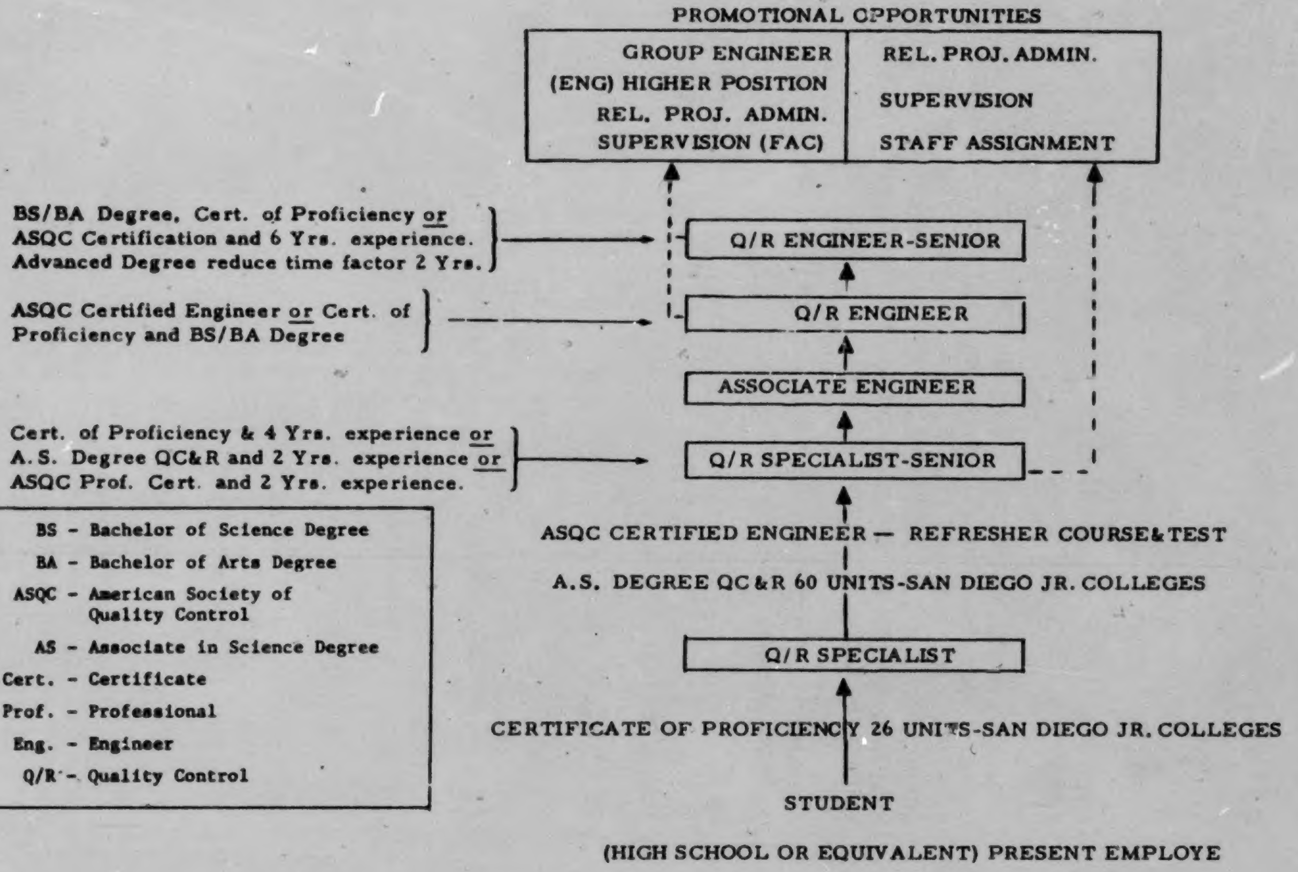
Statistical Clerk - Perform elementary data compilation.

The chart of job-entry positions is not for any single industry, but is applicable to all 21 industries delineated in the structure of manufacturing section contained in this Manual.

Also, it is not the intent to concentrate on job-entry skills only. The skills and knowledges obtained in the area of inspection and test are applicable to the upper echelons of quality control level career fields as well.

Although no specific information is shown within the career field of quality control about quality assurance, it would seem to warrant a brief consideration.

Quality assurance is often confused, sometimes purposefully, with quality control. Quality assurance is viewed as being a higher-order operation of quality programming starting at the upper end of systems engineering, commonly called systems architecture. This assurance field is comprehensive in total dimension of quality, be it design, selection or operation. The programming necessitates multi-disciplinary teams being utilized in systems


PROMOTIONAL OPPORTUNITIES
GROUP ENGINEER
(ENG) HIGHER POSITION
REL. PROJ. ADMIN.
SUPERVISION (FAC)
REL. PROJ. ADMIN.
SUPERVISION
STAFF ASSIGNMENT
BS/BA Degree, Cert. of Proficiency or ASQC Certification and 6 Yrs. experience. Advanced Degree reduce time factor 2 Yrs.
Q/R ENGINEER-SENIOR
ASQC Certified Engineer or Cert. of Proficiency and BS/BA Degree
Q/R ENGINEER
ASSOCIATE ENGINEER
Cert. of Proficiency & 4 Yrs. experience or A. S. Degree QC&R and 2 Yrs. experience or ASQC Prof. Cert. and 2 Yrs. experience.
Q/R SPECIALIST-SENIOR
ASQC CERTIFIED ENGINEER — REFRESHER COURSE& TEST
A.S. DEGREE QC&R 60 UNITS-SAN DIEGO JR. COLLEGES
Q/R SPECIALIST
CERTIFICATE OF PROFICIENCY 26 UNITS-SAN DIEGO JR. COLLEGES
STUDENT
(HIGH SCHOOL OR EQUIVALENT) PRESENT EMPLOYE

BS	Bachelor of Science Degree
BA	Bachelor of Arts Degree
ASQC	American Society of Quality Control
AS	Associate in Science Degree
Cert.	Certificate
Prof.	Professional
Eng.	Engineer
Q/R	Quality Control

Figure 3

QUALITY CONTROL CAREER FIELD

activities. Quality control, inspection and test are definitely the building blocks of this field, but so are reliability, maintainability, cost effectiveness and logistics activities. The main difference between quality control and quality assurance is concerned with any regular mechanical, electrical or other system, but, also includes the human operator as part of the system and the total performance--both specified and unspecified--that the system does and is capable of accomplishing.

In this field, the nearest comparison for careers, occupations or jobs would have to include quality control, inspection and test as a basis. The next echelon would be a generalist or systems engineer in specialties such as hydraulics, electronic, or mechanical systems. The next level would consider total systems in an overall management sense, for example, management of the space program including ground support system, launch system, flight control system, monitoring/communication system and landing system.

The career paths, at this time, are not well defined above quality control and systems architecture levels. This level of the expanded career field is mentioned for purposes of information and for later use in educational-career oriented endeavors.

Specific Occupational Preparation Subject Matter

INTRODUCTION

This section of the Manual contains subject matter related to what is called "hard-skills" acquisition. These skills and knowledge will be acquired in the areas of:

1. Blueprint Reading
2. Statistics
3. Mechanical Measurement
4. Electrical Measurement
5. Chemical Measurement

The wide range of related information contained in the first section of this Manual, aids the students to better understand what they are about to learn relative to: function; the manner and mode of the format; and, the kinds of skills and knowledge in the manufacturing Enterprise Career Field of Quality Control and Inspection.

The purpose of study in this program is for immediate job entry. Purposes of pursuing advanced formal education in this field or related career fields can be secured after basic knowledge and skills are learned.

BLUEPRINT READING

DIMENSIONS AND TOLERANCES

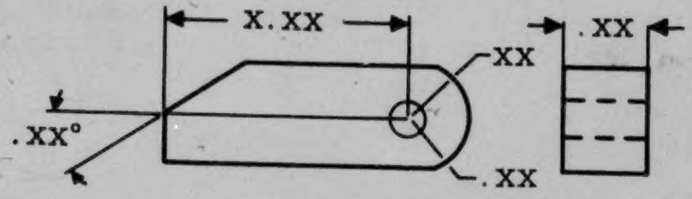
The effectiveness of a quality control inspector is highly dependent on the ability to understand industrial hardware specifications and drawing concepts. It is therefore necessary to review the basics of dimensions and tolerances.

A blueprint contains all the manufacturing requirements for the part being produced, either by direct notation or by reference to other documents and standards. In industry, the blueprint is also called an "engineering drawing," "drawing," or "print." Each of these will bring similar responses to experienced workers. They will be used interchangeably in this resource guide.

The blueprint is also used to inspect a part received from outside sources, during manufacturing, and at the completion of fabrication. Unless deviations or exceptions are issued by engineering, the drawing is the main authority for acceptance or rejection.

DIMENSIONS

Dimensions given on a blueprint describe the geometric features of the part and mean angular units as well as linear units. The following sketch is an example of dimensioning:



Tolerances are used for two purposes: one, to allow the part to be manufactured to within a plus or minus of its design and two, to insist that the part be manufactured to within a tolerated dimension. The reason for these tolerances is usually because the part must fit with or in another part.

TOLERANCES

Tolerances are allowable variations in the dimensions given on a blueprint. These variations must be considered and taken into account by the manufacturer and the inspector.

The design engineer assigns tolerances to a dimension based on the anticipated use of the part. A critical part in a high precision machine might have to fit a matching part within .001 inch, while a nonfunctional part in the same machine might be acceptable if it is within .01 inch of its basic dimension. Assigned tolerances are never smaller than needed to do the job, since manufacturing costs rise rapidly as tolerances decrease.

Therefore, a tolerance is the total amount that the dimension may be permitted to vary or it is the total amount between the maximum and minimum limiting dimensions. A common way to show a toleranced dimension on a blueprint is:

$$2.145 \pm .004$$

This means that an acceptable measurement obtained by the inspector can be no greater than 2.149 nor less than 2.141. This is achieved by the following arithmetical addition and subtraction:

$$\begin{array}{r} 2.145 \\ +.004 \\ \hline 2.149 \end{array} \qquad \text{and} \qquad \begin{array}{r} 2.145 \\ -.004 \\ \hline 2.141 \end{array}$$

The total amount between these extremes is the tolerance, .008, which is the total amount that the dimension may vary.

The tolerance is not always split evening between plus and minus values. Since the assigned tolerance reflects the use of the part, it often happens that more leeway is allowed on one side of the basic dimension than on the other side. For example:

$$2.145^{+.003}_{-.005} \quad \text{or} \quad 2.145^{+.006}_{-.002} \quad \text{or} \quad 2.145^{+.000}_{-.008}$$

Toleranced dimensions may appear on the blueprint in other forms.

For example, $2.145^{+.003}_{-.005}$

can be expressed as a pair of limiting dimensions and stacked vertically, as follows:

2.148
2.140

or placed side by side with a dash between, such as:

2.140-2.148

TOLERANCE BLOCK

Often drawings do not list dimensions directly on the figure of the part and would lead the student to believe there are no apparent tolerances. In such cases, look for a "tolerance block" usually imprinted on the drawing form as part of the title block. It will look something like the following:

TOLERANCES (UNLESS OTHERWISE NOTED ON FACE OF DRAWING)		
.X	=	± .1
.XX	=	± .03
.XXX	=	± .010

Another way of specifying tolerances is by a general note on the face of the drawing. An example is:

NOTE: Unless otherwise noted, all tolerances are ±.010.

Another possible note is:

NOTE: Tolerances are as specified in company standard practices.

Any document, guide, standard, specification, or similar directive relating to manufacturing of the part, should be referenced in a note on the face of the drawing.

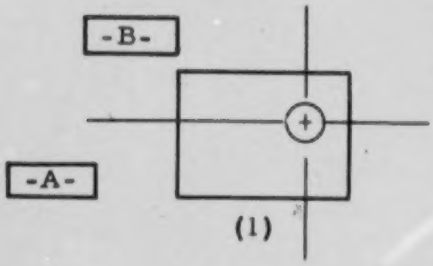
INTERPRETATION OF LIMITS

All dimension limits are considered to be absolute; that is, no measurement that exceeds a limit is acceptable. This may seem elementary, but consider the following example:

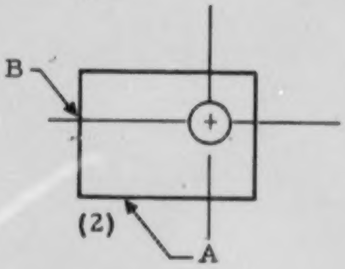
> A toleranced dimension of 1.625 ± .003 on the blueprint means that the limiting dimensions are 1.622 and 1.628. The argument could be made that a measurement of 1.6283 is acceptable because it rounds off to 1.628, but that is not the case. Any measurement above 1.628, even the three ten-thousandths, is unacceptable. On the lower end of the tolerance, a measurement of 1.6218 is equally unacceptable even though it rounds up to 1.622.

DATUMS

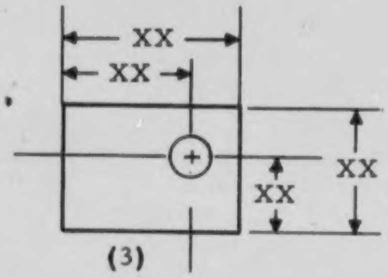
A datum is a stable feature such as a surface, line, or point-on-a-part, used as a starting point for specifying dimensions or for taking measurements. When datums are identified on a blueprint, they are noted with a capital letter, A, B, C, etc. Examples are:



(1)



(2)



(3)

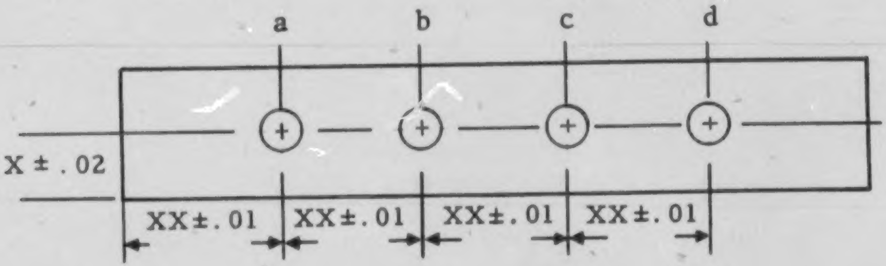
The sketch number (3) is the best description of datum line, since it is obvious that dimensions are placed at the right side and at the top of the part, there is no need to label these datum surfaces or planes.

Both of the other sketches ((1) and (2)) are common examples of the use of letters to identify datums. One method in which each letter is enclosed in a heavy black box and attached to the datum. The second method in which arrows are simply used to identify the corresponding datum surfaces.

Plane surfaces are commonly used as datums, as are other features, for example, a cylindrical surface, a center line, or a center plane. Whatever the datum, it must be identifiable and accessible to be useful for measuring.

TOLERANCE BUILDUP

Tolerance buildup occurs when several dimensions are placed sequentially together, each having specific tolerances, causing the tolerances of each to add together resulting in a "buildup." This is commonly called chain dimensioning and is illustrated in the sketch below as each feature being dimensioned from a neighboring feature rather than from a datum.



The location of hole "a" can vary ±.01 with respect to the left edge of the part, hole "b" can vary ±.01 with respect to hole "a".

The location of hole "d" could vary with respect to the left edge of the part and still be in tolerance. The distance that is "tolerable" in this case would be ±.04. This is because the tolerances are additive. If all tolerances between two points in a chain of dimensions are stretched to their limits, the location of one point with respect to the other will vary by the sum of the intermediate tolerances. In this case it was ±.01 ±.01 ±.01 = ±.04, the tolerance range of hole "d" with respect to the left edge.

Variations of chain dimensions can be used, such as direct measurements from one hole to another (a and d) or change to datum dimensioning by using hole "a" as a datum and locating holes "b" and "c" as well as "d" by direct dimensioning from "a". The dimension between "a" and any of the other holes is now directly controlled to a tolerance of ±.01. Datum dimensioning is commonly seen on blueprints since it controls critical dimensions with less buildup of tolerances.

STUDENT ACTIVITIES

1. Sketch two diagrams with the following dimensions:

   1.038 .002 and $3.875^{+.005}_{-.010}$

   and determine which of the following is correct:

   1.038-1.040 or $\begin{matrix}3.880\\3.865\end{matrix}$

2. Given a toleranced dimension of $2.150^{+.005}_{-.003}$, which of the following measurements are out of tolerance? Answer this question from the following choices.

   2.153 2.105 2.1550
   2.146 2.1494 2.1551

   Refer to the lesson on interpretation of limits for direction to the proper response.

3. Basic drawings (blueprints) should be reviewed by the student to seek out the different uses of datum descriptions.

4. Sketch several features on a form and place several dimensions in a line. Then add the tolerances of these many dimensions to gain confidence in the proper method of tolerance buildup.

POSITION TOLERANCE, COORDINATE TOLERANCING, AND POLAR COORDINATE

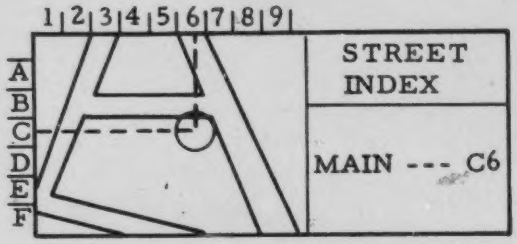
Much of the time that an inspector uses is spent on measuring the position of features (holes, faces, notches, etc.) with respect to each other or to a datum. Generally, this is necessary to ensure that the form does not deviate more than a prescribed amount from an established pattern or geometric shape.

The inspector must therefore be familiar with positional tolerancing and form tolerancing - what they are and how they are noted or specified on a blueprint.

POSITIONAL TOLERANCE is the allowable variation in the specified position of a feature in relation to some other feature or datum.

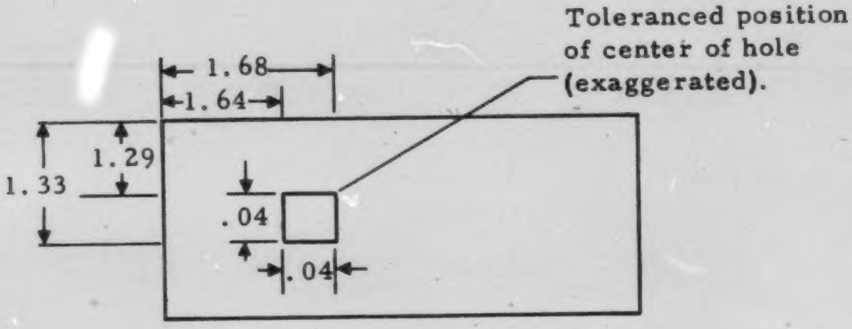
An example of positional tolerancing is the distance that the center of a hole may deviate from an ideal or exact position. This means the actual position of the center point must fall within the positional tolerance. Dimensions do not have to have any bearing whatsoever on the shape or form of the part but provide positional tolerance.

COORDINATE TOLERANCING involves the use of coordinates to position a feature. An example of coordinates is illustrated on the following sketch:



Main street on this map sketch is located at the intersection of coordinates "C" and "6". Notice that the coordinates are initiated at the left edge and the top edge. These are equivalent to the datums of a part sketch. Coordinates also occur at 90 degrees or right angles to each other.

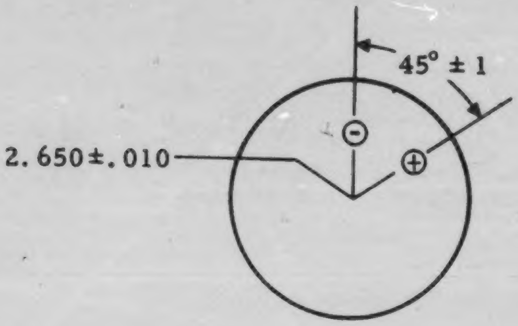
Two toleranced dimensions at right angles to each other will intersect to give a toleranced position for the feature.


Toleranced position of center of hole (exaggerated).

The exaggerated dimensional differences show the effect of coordinate tolerancing on the location of a hole. The acceptable area for the center point is a square, .04 by .04. In the above example, the tolerance is the same in both directions giving a square tolerance zone. If the tolerance is greater in one direction than the other, the shape of the tolerance zone would be rectangular. The tolerance zone resulting from two toleranced coordinates is always square or rectangular (except when dimensions are in polar coordinates).

POLAR COORDINATES

Polar dimensions (coordinates) consist of a direction and a distance from a point (or pole). The directional coordinate is given in degrees of rotation around a pole, and the distance from a pole is a simple linear dimension.



In the example of polar coordinates above, the holes are positioned radially by the measurement from the center point. The second hole is also positioned by the angular measurement from the first hole.

The tolerance zone is wedge shaped, as it is for all polar coordinate tolerances.

Figure A

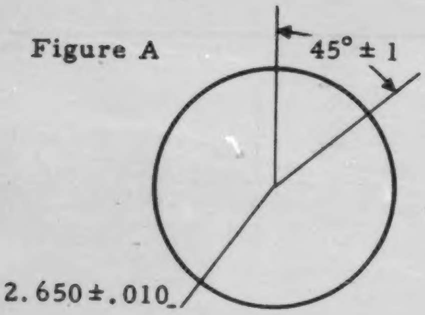


Figure B

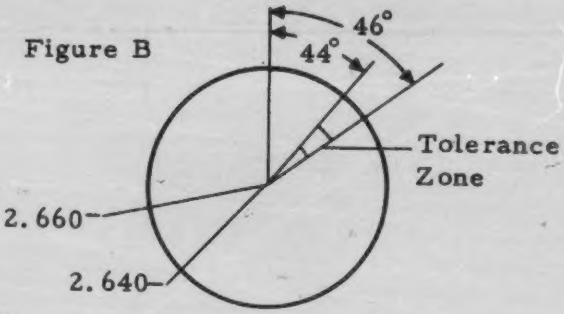
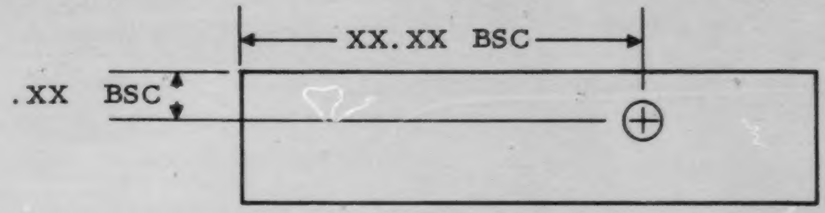


Figure A shows polar coordinate tolerances as you would see them on a blueprint. Figure B is an exaggerated picture of the resulting tolerance zone.

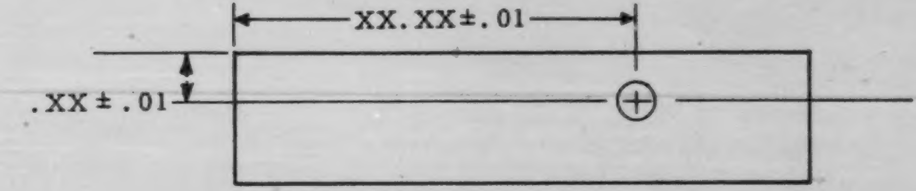
TRUE POSITION TOLERANCING

True position of a feature is its basic or theoretically exact position.

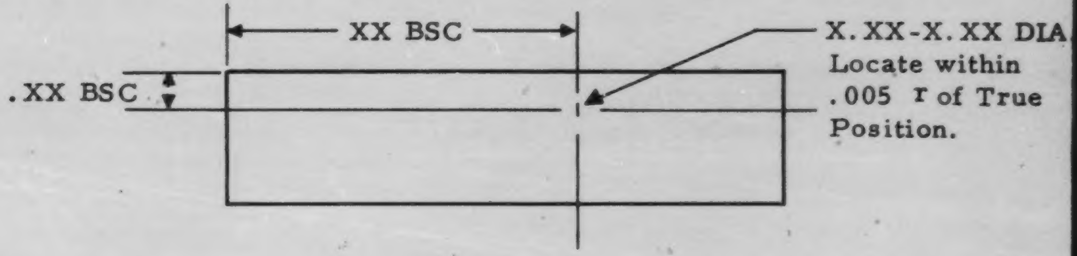
The true position of a hole is determined by basic, untoleranced dimensions. For example:



However, as we learned earlier, untoleranced dimensions by themselves are useless because manufacturing and inspection processes always include errors. The problem is overcome by adding tolerances to the basic dimensions as shown in the following sketch:



In true position tolerancing, the exact position of the feature is established first, using basic dimensions, and then by applying the tolerance directly to the feature. To locate a hole within .005 radius of true position, the sketch might look like:

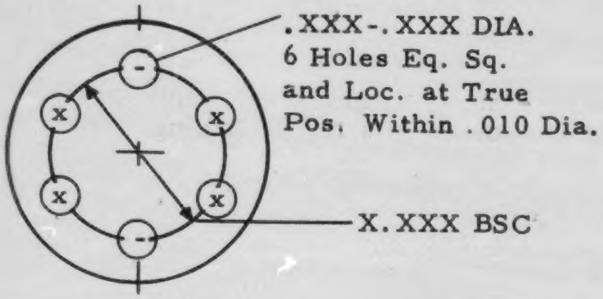


The first statement in the notation, "X.XX-X.XX DIA." is the toleranced hole size. The second part of the notation is the true position tolerance.

A blueprint can also express the true position tolerance in terms of "diameter" rather than radius such as:

"LOCATE AT TRUE POSITION WITHIN .010 DIA."

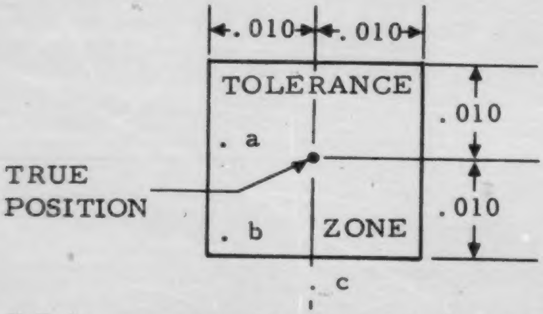
True position tolerancing has been used to locate a symmetrical hole pattern.



First notice that the hole diameters are toleranced by high-low dimensions (.XXX-.XXX DIA.). The six holes are equally spaced (6 holes Eq.Sp.) with centers located within circular tolerance zines of .010 diameter whose centers are at true positions (LOC AT TRUE POS WITHIN .010 DIA).

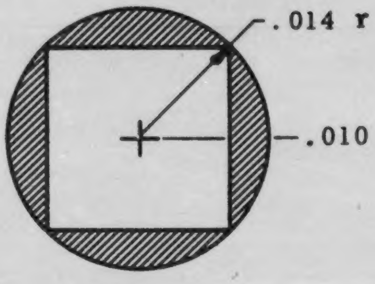
Other examples of tolerance zones are:

The Square Tolerance Zone



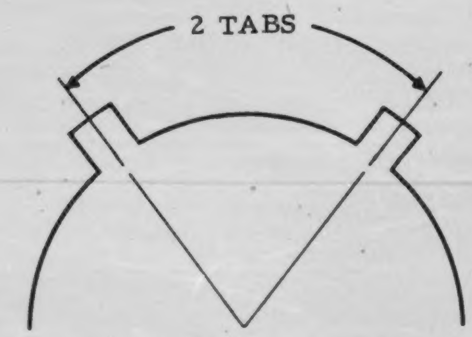
Point "a" is an acceptable location for the toleranced feature. Point "b" is also acceptable even though it is located in the extreme corner. Point "c" is not acceptable since it is located outside the square zone.

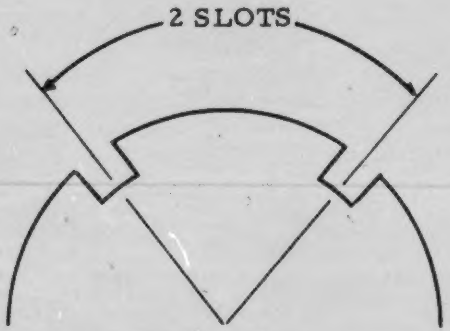
A true position tolerance of .014r in the following sketch would give a circular tolerance zone into which the square zone would just fit.



The shaded areas represent the added locations available with true positions tolerancing. The result is fewer rejections.

True position tolerancing is not used exclusively for locating round features such as holes. The location of tabs and slots can also be toleranced in relation to the true position of their center planes.





In these cases, tolerances express the acceptable variation of the center plane to each side of its true position. The statement will look like this:

"LOC WITHIN .015 EITHER SIDE OF TRUE POS."

Whether tolerancing is to the true position of a hole, a tab, or any similar feature, the true position must be established by basic dimensions with respect to the datum.

SYMBOLS

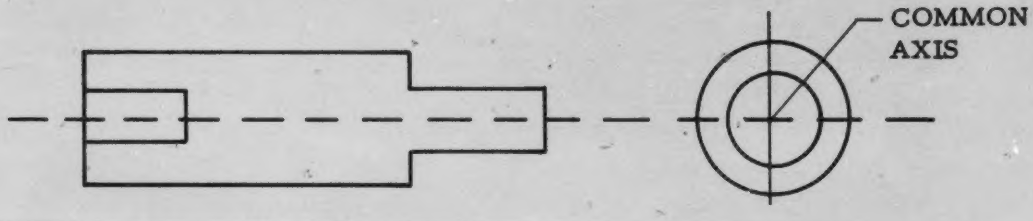
Positional and form tolerances are often expressed in abbreviated form to simplify notations on the face of the blueprint. The following block, keyed to a particular hole on the drawing means the same as, "LOCATE WITHIN .005 r OF TRUE POS IN RELATION TO SURFACE A."

⊕	A	.005 r

The first square always contains a symbol that represents the applicable geometric characteristics, in this case, ⊕, meaning TRUE POSITION.

Another common symbol is ◎. It is used to express concentricity.

Concentricity is a condition in which two or more surfaces of revolution (cylinders, cones, etc.) have a common axis.



The degree to which the axis may deviate from a datum axis is the tolerance. As in the positioning of holes, or slots, the tolerance is expressed either by note or with symbols.

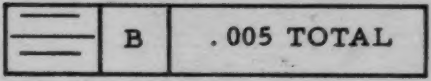
The following symbol gives a concentricity tolerance:

◎	A	.010 DIA.

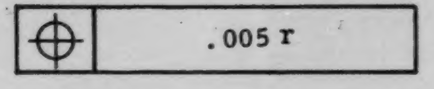
A third positional tolerancing includes symmetry. This is a condition in which the feature is distributed symmetrically on both sides of a central plane of datum.

Symmetry tolerance is expressed by a note or by the symbol ≡. A typical note might read, "SYMMETRICAL WITH DATUM A WITHIN .008 TOTAL." "TOTAL" means that the stated tolerance is divided evenly on both sides of the datum plane.

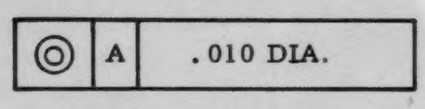
This note converts to:



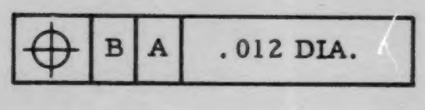
Other examples of symbolic expressions are:



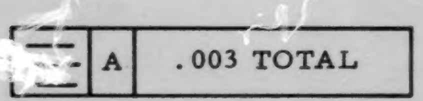
LOCATE WITHIN .005 RADIUS OF TRUE POSITION



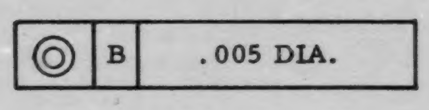
CONCENTRIC TO A WITHIN .010 DIAMETER



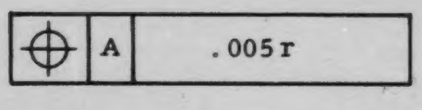
LOCATE AT TRUE POSITION WITHIN .102 DIAMETER IN RELATION TO DATUM B AND A



SYMMETRICAL WITH A WITHIN .003 TOTAL



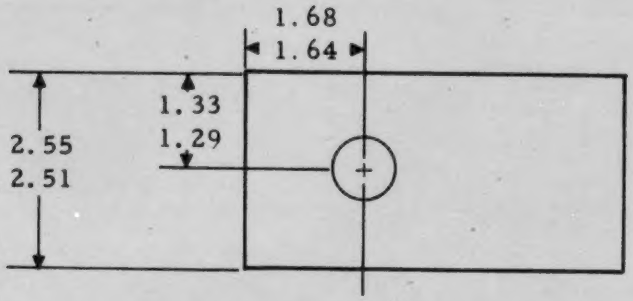
CONCENTRIC TO B WITHIN .005 DIAMETER



LOCATE WITHIN .005 RADIUS OF TRUE POSITION IN RELATION TO DATUM A

STUDENT ACTIVITIES

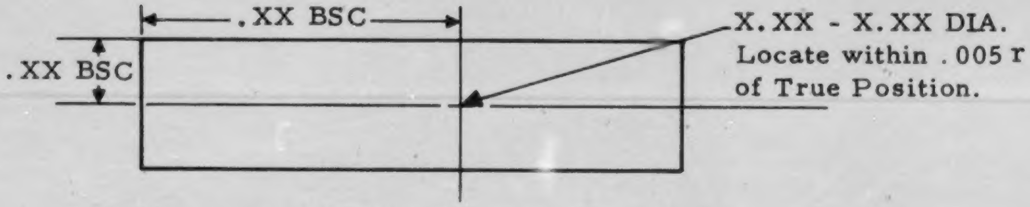
1. Review the following sketch and determine if the dimensions shown provide positional tolerances.



For direction to the answer, review the preceding pages on basic tolerancing beginning with page 31.

2. Read a local street map and mark the coordinates of your high school location, the home, fire station, or other points of interest.

3. The student should determine the shape of the tolerance zone for the hole location in the following sketch.



4. Write the interpretation for each of the following true position tolerance symbols on a sheet of paper, then turn to the text for your answers.

a. ⌖ | .021 DIA.

b. ⌖ | A | .010 r

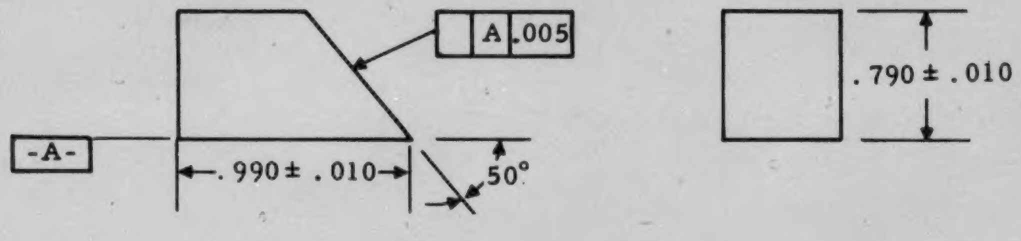
c. ⌖ | B | C | A | .030 DIA.

5. Change the following note to the corresponding symbolic expression:

"SYMMETRICAL WITH DATUM PLANE B WITHIN .005 TOTAL."

6. Review the material to determine if roundness control can be limited to only certain areas of a part.

7. The student should review angularity requirements and answer the following questions:



   a. What type of form is being controlled?

   b. What is the total horizontal size tolerance?

   c. What is the total angular tolerance?

   d. What is the approximate maximum distance that the angular tolerance zone can shift to right or left and still remain within the limits of size?

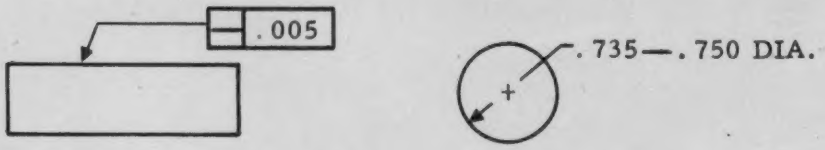
8. Summarize and evaluate the various position tolerancing methods and relate the associated symbols with each. Check these by reviewing a drawing from an industrial manufactured part.

FORM TOLERANCING

Form tolerancing controls the conditions of shape or form, such as:

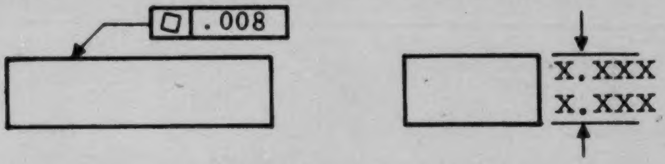
- Straightness
- Flatness
- Roundness
- Cylindricity
- Profile
- Angularity
- Parallelism
- Perpendicularity
- Runout

Straightness - the symbol for straightness is "____". A drawing that specifies this symbol is as follows:



In note form, the tolerance above would read, "STRAIGHT WITHIN .005 TOTAL."

Flatness - the symbol for flatness is " ▱ ". A drawing that specified this flatness symbol is as follows:



In note form, the tolerance above would read, FLAT WITHIN .008 TOTAL."

This flatness tolerance means that all points on the surface being controlled must be between two parallel planes spaced at .008 apart.

Roundness - The control of roundness is similar to straightness except that two concentric circles form the boundaries rather than two parallel lines.

The symbol for roundness is "○".

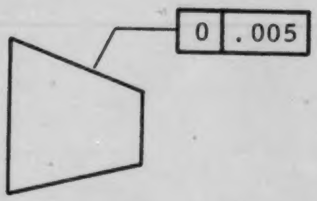
Roundness is controlled by tolerancing any round section from a cylinder, a cone, or a sphere.

CYLINDER

CONE

SPHERE

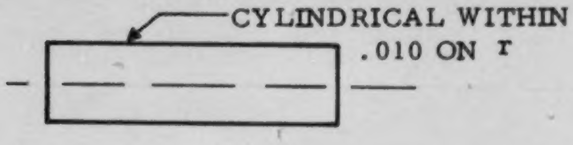
The tolerance callout appears as follows:



OR IN NOTE FORM { ROUND WITHIN .005 ON r

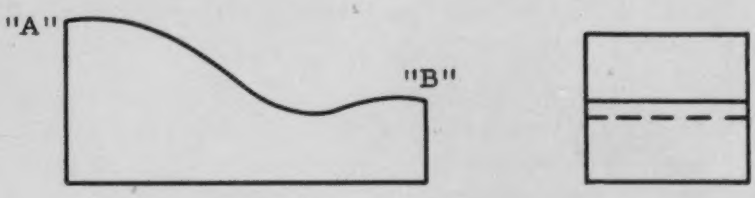
The term "ON r" in the note means that two concentric circles will have a radius difference equal to the stated tolerance.

Cylindricity - the symbol for cylindricity is "⌭". An example of a drawing illustration is as follows:



This means that the cylindrical surface must be between two concentric cylinders, one having a radius .010 larger than the other.

Profile - Profile tolerancing involves either a line or a surface.



Using the part shown, for example, either the entire surface between "A" and "B" can be toleranced, or a line between "A" and "B" formed by a parallel section through the part can be toleranced.

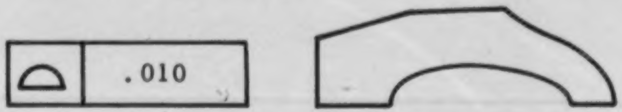
A profile may consist of one or more radius curves, straight lines, angles, and irregular curves. Therefore, profile tolerances control both shape and size.

Profile symbols are: "⌒" for a line

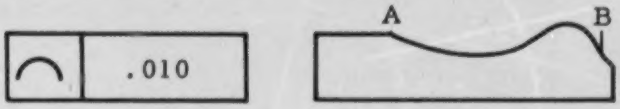
"⌓" for a surface.

Examples are:

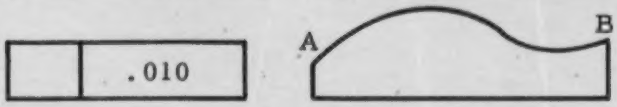
ALL AROUND



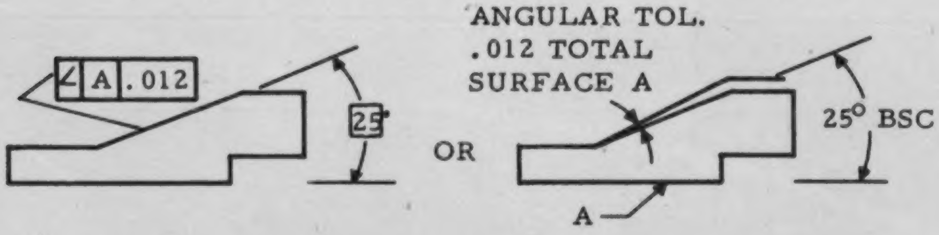
BETWEEN A & B



BETWEEN A & B



Angularity - A form of tolerancing that requires a datum plane or axis to be specified from which the angle is measured. The symbol for angularity is "∠". In the example:

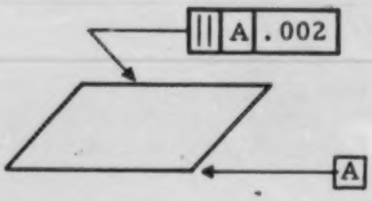


This angularity tolerance means that the angular surface must be between two parallel planes, .012 apart, and angled at 25 degrees to datum surface A.

Parallelism - The condition in which all parts of a line or surface are the same distance from a datum axis or plane. It is controlled by the assignment of a tolerance within which the distance from the datum may be allowed to vary.

The symbol for parallelism is "||" or "/ /".

An example drawing is:



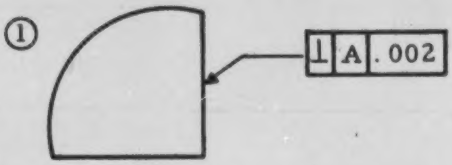
The example drawing specifies that all points on the upper surface must be between two planes that are .002 apart and are parallel to surface A.

In the absence of a more restrictive flatness tolerance, a parallelism tolerance also controls flatness.

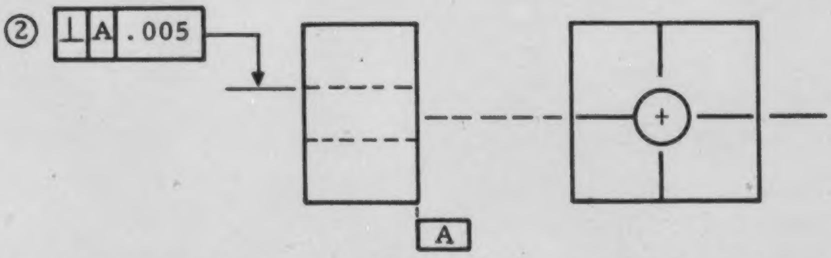
Perpendicularity - is always specified in relation to a datum. It is the condition in which a surface, line, or axis is at right angles (90 degrees) to the reference feature.

The symbol of perpendicularity is "⊥".

Examples 1 and 2 of perpendicularity illustration are:



OR PERP. TO SURF. A
WITHIN .002 TOTAL

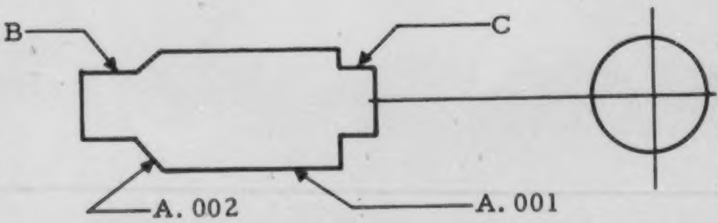


Example 1 means that all points on the controlled surface must be between two planes, .002 apart, that are perpendicular to surface A.

Example 2 illustrates perpendicular tolerancing of the axis of a hole in relation to a surface. This means that the axis of the hole must be located within a cylindrical zone, .005 in diameter, that is perpendicular to surface A.

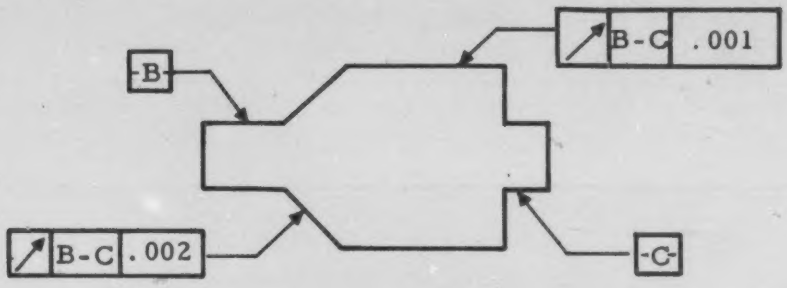
Runout - A tolerance that controls the relationship of two or more features that have a common axis. The symbol for runout is, "↗".

The runout tolerance notation on a blueprint will identify the datum axis about which additional features are controlled. An example to illustrate this is:



When mounted on Datums
B and C Designated
Surfaces must be within
Total Runout (FIR)
Specified by A.

The initials "FIR" are usually used when specifying a runout tolerance in note form. It means "full indicator reading." When "TIR" is used, it means "total indicator reading." If symbols are used in lieu of the note in the example above it would appear as follows:



The run symbol is the least descriptive of its function, although it does suggest the contact point of an indicator gauge, the type of equipment used to measure runout.

STUDENT ACTIVITIES

1. Obtain a blueprint from a company or local commercial manufacturing firm that produces metal products. Identify the various form tolerances and mark them. Check your results with the lesson on form tolerancing in the resource guide.

2. Practice the different symbol of form tolerances on sketches of an object in your home.

3. Enroll in a blueprint reading or a mechanical drawing course to get practice in using the different form tolerance methods.

4. Visit the metal shop in your high school and ask the teacher to illustrate the various methods of forms on items in the shop. Perhaps you may enroll in a class to practice making the different forms.

SURFACE TEXTURE

Surface roughness plays an important part in any assembly where friction and sliding ability are involved. The surface finish or texture of a part may be specified on the blueprint for any one of a number of reasons. Close tolerance components require close control of surface finish; surfaces subject to friction also require special attention. Even appearance is affected by surface texture and where appearance is important, the texture is specified.

1. Surface roughness - is surface irregularities in a consistent pattern produced by machining or processing.

Departures from the ideal smooth surface are:

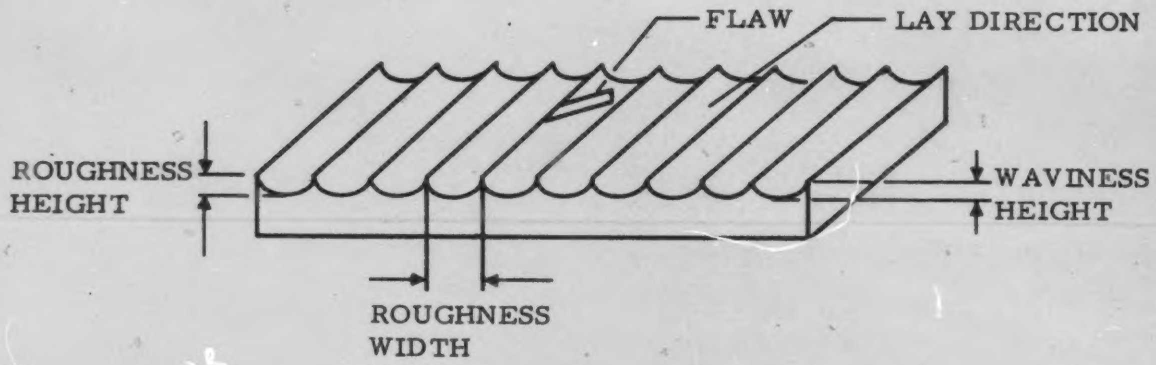
Roughness - finely spaced surface irregularities in a consistent pattern produced by machining or processing.

Waviness - an irregular surface condition of greater spacing than roughness.

Flaws - irregularities that do not appear in a consistent pattern.

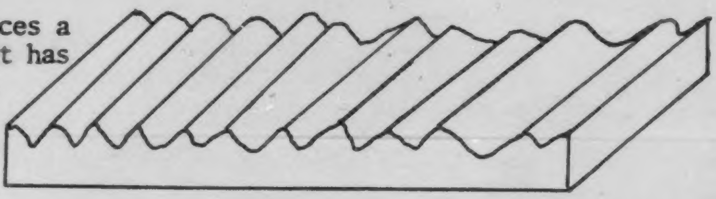
Lay - a predominant direction of surface pattern.

2. The following sketch is presented to illustrate the departures from the ideal smooth surface:

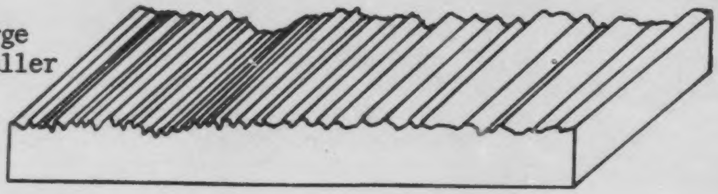


Some examples of surface texture produced by various production processes and machines are as follows in exaggerated form:

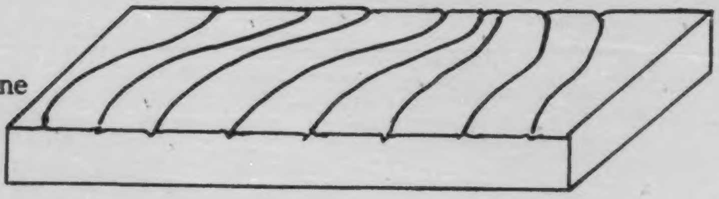
Lathe machining - produces a crystalline surface that has peaks and deep valleys.



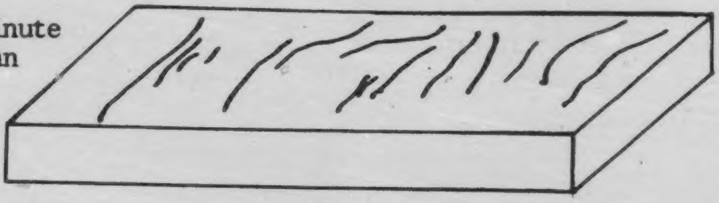
Grinding - reduces large peaks but produces smaller ones.



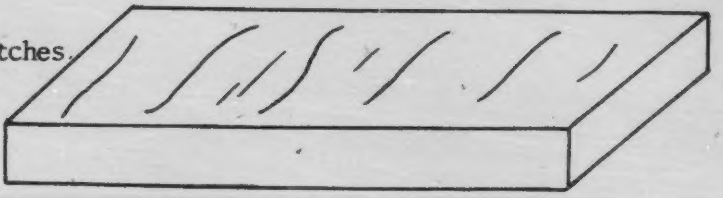
Honing - produces fine scratches.



Lapping - leaves minute scratches finer than honing.



Gauge block - surfaces have very shallow scratches.



Buffing - produces heat to bring about "plastic flow" and aids reflectivity but reduces quality of surface flatness.

Texture is used to reduce friction and reduce wear for the following reasons:

A surface too rough causes excessive wear.

A surface too smooth will not allow lubricant retention.

A surface too smooth is a poor compliment in metrology.

NOTE: A buffed or polished surface may have good reflective qualities but does not have a good surface finish.

3. Surface texture (finish) symbols are listed and illustrated below:

√ Shown on drawings to indicate a surface to be machined to the roughness height stated in the blueprint finish block.

63 √ Roughness Height Rating - The surface roughness height, expressed by a numerical rating, placed adjacent to, and at the left of the long leg as shown. The specification of one number indicates the maximum permissable sustained roughness beight rating. Any lesser rating is acceptable.

$\overset{63}{32}\surd$ Maximum and Minimum Ratings - Maximum and minimum roughness height ratings shall indicate permissable range. The maximum rating shall be placed above the minimum as shown.

$63\surd\overline{\;.002\;}$ Waviness Height - The waviness height value, in inches, is placed above extension line as shown. The value indicates maximum allowable waviness height.

Other symbols for lay are:

$\sqrt{\perp}$ - Lay is perpendicular.

$\sqrt{\shortparallel}$ - Lay is parallel.

$\sqrt{X}$ - Lay is angular in both directions.

$\sqrt{M}$ - Lay is multidirectional

$\sqrt{C}$ - Lay is circular.

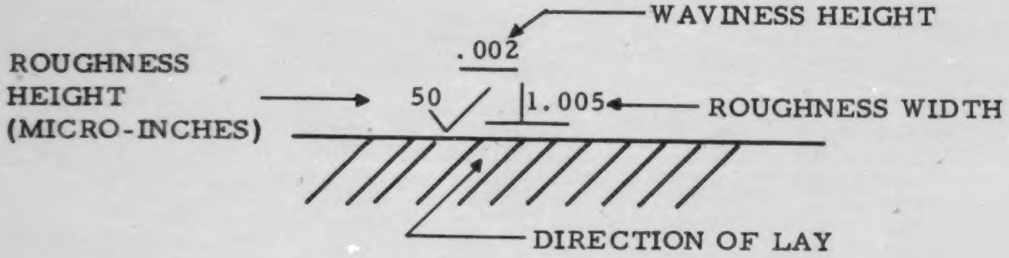
$\sqrt{R}$ - Lay is approximately radial.

NOTE: One final point regarding surface symbols is when only roughness height is specified, the symbol is often abbreviated to a simple check mark such as $32\surd$.

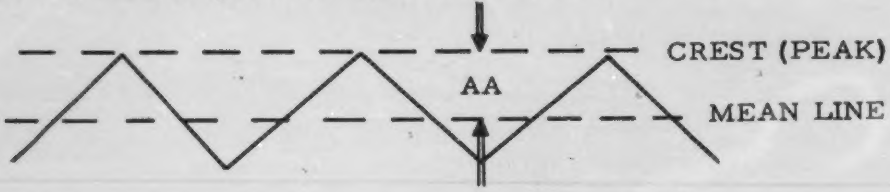
This simplified symbol means that there is no requirement to limit waviness. It will be necessary, however, to determine lay either visually or by some experimental means, and to establish a roughness width cutoff value to set on the measuring equipment, usually the standard value. (.030).

In most cases, when all surfaces of a part have the same surface roughness and waviness requirements, the finish symbol appears only in the finish block of the blueprint. In cases of varying surface roughness and waviness, the most predominant surface requirement appears in the finish block of the blueprint. In cases of varying surface roughness and waviness, the most predominant surface requirement appears in the finish block of the blueprint with the exceptions being shown by placing the finish symbol on the exception surface or by placing the finish symbol on an extension line from the surface to which it applies.

A typical drawing illustration depicting drawing symbols for surface texture is as follows:



4. Surface finish is specified by the Arithmetical Average (AA) which designates the distance between the mean line and the crest or peaks as illustrated below:



Surface finish is measured in microinches (MU) and is expressed as 0.000001 inch or 1 x 10 - 6th power.

Precautions: Before determining surface texture measuring methods, the texture parameters or needs must be considered. These are:

The average range of departures from the average of the high and low points of the surface.

The height of the most protruding element (peaks) of the surface and the frequency of occurrence.

The interrelations between the waves and the roughness departures from the theoretical surface.

The pattern of the surface and its orientation.

The cross-sectional form of the repetitive form irregularities.

The presence of random discontinuities.

Some Common Measurement Methods:

A. Tactual Surface Texture Scales (Sight and feel) - This is evaluating roughness by sight or fingertip by using a scale with samples of comparable pattern.

B. Electro-Mechanical Stylus - A needletype instrument (Stylus) is moved along the selected surface element. The stylus is connected with a pickup which is maintained in a controlled level, yet permits the stylus to follow the surface contour. Mechanical deflections are converted to electronic signals which are amplified and displayed on a meter or chart. Types are:

Pickup head with skid or shoe for average roughness indications.

Pickup head with support roll to indicate average deviations from envelop surface.

Skidless pickup head extraneously supported for average indications in restricted areas.

Datum supported pickup head for recorded indications of the entire surface texture.

C. Optical Systems - Optical comparators are used to visually determine roughness on an enlarged scaled screen.

To summarize the methods of surface texture measurement, the following table is presented for clarity:

METHOD	EQUIPMENT USED	REMARKS
1. Visual or tactile comparison.	Specimen blocks or gages.	By eye or feel (touch).
2. Visual with a microscope	Microscope with two stages.	Visual.
3. Surface tracing.	Stylus measuring instrument with averaging amplifier.	Most widely used method.
4. Surface profile tracing with recording.	Profile tracing instrument with amplifier.	Gives more detail than a single average.
5. Viewing under magnification.	Regular light microscope.	Where stylus is not practical.
6. Light sectioning.	Light section microscope.	Where stylus is not practical.
7. Interferometric measurements.	Reflected light interference microscope.	Where and when equipment is available.
8. Electron microscopy.	Electron microscope.	For minute detail.

STUDENT ACTIVITIES

1. Answer the following questions:

   (a) What occurs when a surface is too rough? Too smooth?

   (b) What is the unit of measure for surface texture?

   (c) What is the actual measurement method?

2. Review a textbook on different finishes available in the school library.

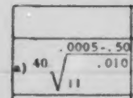
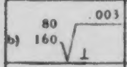
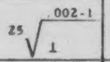
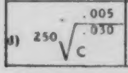
3. Visit the metal shop in your school or perhaps enroll in a course that is available to get firsthand sight and feel of different metal finishes.

4. Ask the metal shop teacher to demonstrate the different types of finishes obtained by lathe work, grinding, honing, buffing.

5. Perhaps the metal shop is supplied with surface texture feeler gages. If one is available practice checking finishes by using the gage and comparing a machined part.

6. Visit a local machine shop where finished metals require surface finish control. Ask for demonstrations of the different equipment that is used to measure surface roughness.

7. As a practical exercise, after studying the surface finish lesson, try to complete the following table and supply the missing values:

	ROUNDNESS HEIGHT	WAVINESS HEIGHT	WAVINESS WIDTH	ROUGHNESS WIDTH CUTOFF	LAY
a) 					
b) 					
c) 					
d) 					

STUDENT NOTE: See the next page for answers after you have exhausted your efforts.

ANSWERS TO ACTIVITY EXERCISE #7

	ROUNDNESS HEIGHT	WAVINESS HEIGHT	WAVINESS WIDTH	ROUGHNESS WIDTH CUTOFF	LAY
.0005-.50 a) 40 √ .010 ∥	Millionths ↓ 40	.0005	.50	.010	Parallel
80 .003 b) 160 √ ⊥	80 Min. 160 Max.	.003	Not Specified	.030 (Understood)	Perpen-dicular
.002-1 c) 25 √ .100 ⊥	25	.002	1	.100	Perpen-dicular
.005 d) 250 √ .030 C	250	.005	Not Specified	.030	Circular

MECHANICAL MEASUREMENT

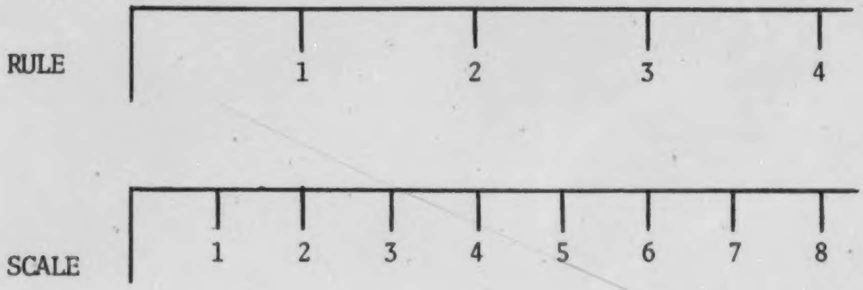
SCALED INSTRUMENTS AND ACCESSORIES

The hand measuring devices used in machined parts inspection include both precision and nonprecision instruments. Precision instruments mean measuring devices that have the accuracy and sensitivity to measure dimensions to thousandths and tenths of thousandths of an inch and hundredths and thousandths of a millimeter. Nonprecision instruments mean devices in which the accuracy of measurement largely depends on the ability to line up and read the graduations of a scale.

SCALE VS. RULE

A scale is a measuring device which is graduated for the purpose of increasing or decreasing the size of an object on a drawing. It is also used as a descriptive term such as "the ruler has a scale of..." or "that vernier scale..."

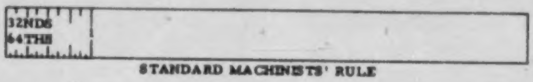
A rule is a measuring device which is graduated in full scale, whatever that particular scale may be. The illustrations shown below are good examples of the basic differences between the scale and the rule.



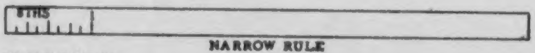
THE STEEL RULE

One of the simplest and most widely used hand measuring devices is the line-graduated steel rule - sometimes erroneously called a scale. Basically, the steel rule is a narrow strip of steel with one or more scales graduated in fractional or decimal inches, or centimeters. It is read by direct comparison of the graduations with an edge or surface. As will be seen later, there are many types and sizes of steel rules. Lengths vary from a fraction of an inch to several feet. Some have a fixed or sliding hook on one end to facilitate alignment of the starting point of the rule with an edge. The short rules usually include a removable clamping shaft or holder to facilitate handling. Some steel rules have fractional inch scales on one side and decimal or metric scales on the other. Likewise, some have conversion charts engraved on the reverse side. The most popular rule - possibly because it's easily carried in a pocket - is the standard six-inch machinist's steel rule.

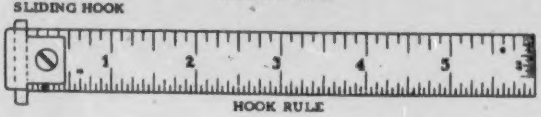
Some typical examples of steel rules are shown:



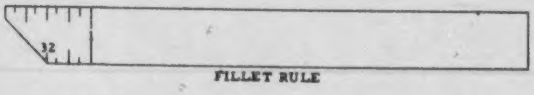
STANDARD MACHINISTS' RULE



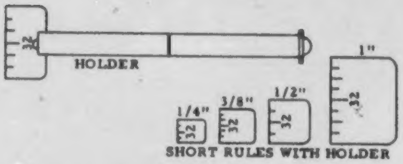
NARROW RULE



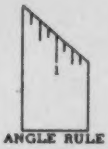
HOOK RULE



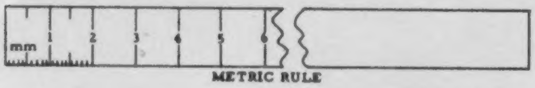
FILLET RULE



SHORT RULES WITH HOLDER



ANGLE RULE

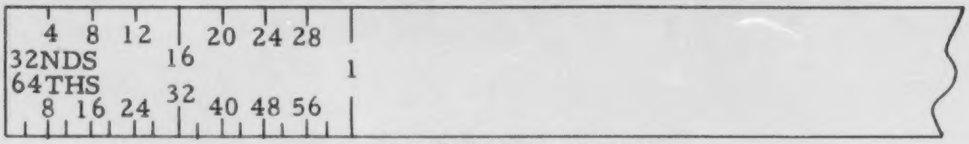


METRIC RULE

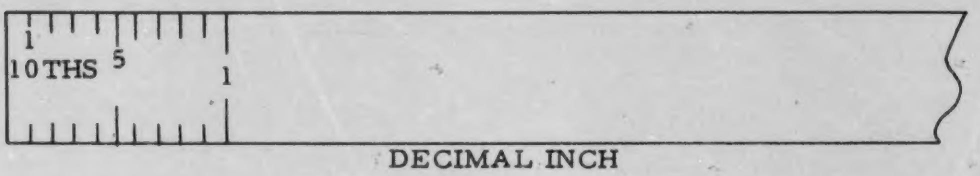
While considering the different steel rules, it should be remembered that fractional inch scales found on steel rules are usually graduated in 8ths, 16ths, 32nds, and 64ths of an inch. Decimal inch scales are available in 10ths and either 50ths or 100ths of an inch. The metric scales are divided into centimeters, millimeters and half millimeters.

SELECTING A STEEL RULE

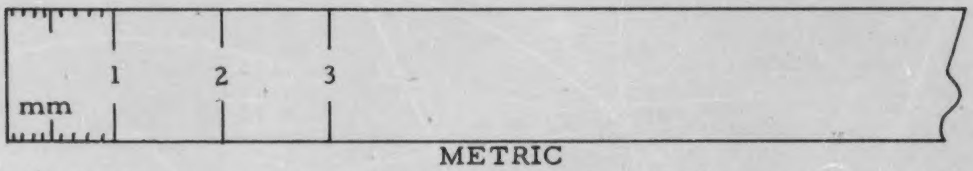
In choosing a steel rule for accomplishing a particular measurement, first select a rule with scales that agree with the part or object to be measured. That is, use fractional inch scales in measuring fractional inch parts, decimal inch scales for decimal parts, and metric scales for metric parts.



FRACTIONAL INCH



DECIMAL INCH

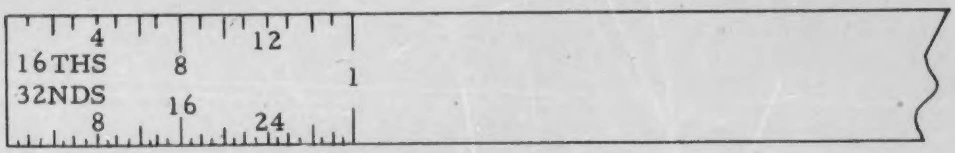


METRIC

Of the three rules illustrated above, as an example, determine which rule would be used to measure a dimension of 44/64 inches.

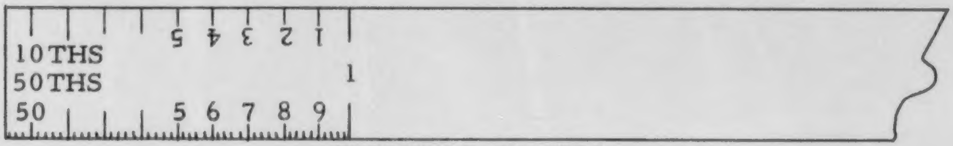
It should be obvious that the rule containing the fractional inch scales is the correct choice since the dimension given is in fractional inches.

It should also be realized that in selecting a rule, no steel rule - or any other line-graduated measuring device for that matter - is capable of controlling the accuracy of measurement to a degree finer than that of the finest graduation on its scale. This is called "discrimination."



If, for example, the finest graduation on the rule is 1/32 inch, the dimension to be measured must be in terms of units not smaller than 32nds of an inch. A dimension in 64ths would fall between graduations and would have to be made or an interpolation made to get the actual dimension. For reliable readings, scale discrimination must be such that guessing or interpolation is held to a minimum.

Which of the following scales provides the finer discrimination?



DECIMAL INCHES

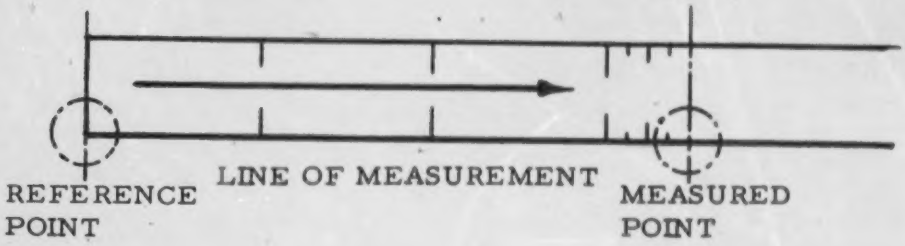
You should realize that the 50ths (.02 inch) scale would provide the finer discrimination.

The next consideration is to select the appropriate type or size of steel rule. If the dimension lies in a recess or cramped area where space does not allow the use of regular size rules, a short rule must be used. If the measurement involves a fillet, a fillet rule is required. A narrow rule may be required in measuring the depth of a narrow slot. Steel rules or excessive length also can be a factor in that they become unwieldly in measuring small objects and short distances, making it difficult to obtain a reliable measurement.

In other words, select the rule that will best do the job. The primary considerations in selecting a steel rule are the physical characteristics and the size or dimensions of the object to be measured. Convenience and adaptability are secondary.

MEASURING WITH A STEEL RULE

All linear measurements, and that includes measuring with a steel rule, are basically point-to-point measurements involving a "reference point" and a "measured point." The "points" in turn may be true points, a pair of lines or edges, two sides, or two planes.



In measuring with a steel rule, the rule is generally held or supported so that scale graduations rest on the line of measurement, with the starting point of the rule aligned with the reference point. The measured point is then read directly from the scale.

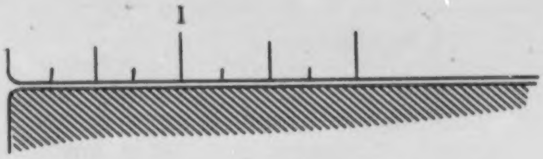
Should the measured point not coincide with a rule graduation, the rule is turned to a successively finer scale until the measured point does coincide with a graduation, or until the required discrimination or the finest scale is reached.

In measuring with a steel rule, it is the measured point that is read to the nearest graduation.

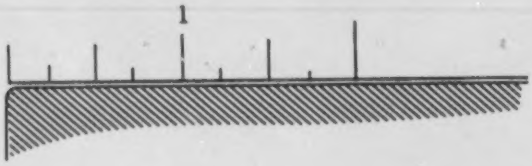
SOURCES OF ERROR

Now that we have an idea of how steel rules are used, look at some possible sources of error in using a steel rule and how they can be avoided. Shown below are some examples of what might be encountered in aligning a steel rule with a reference point.

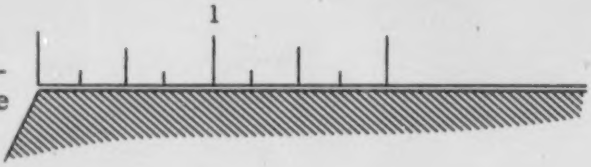
Both rule and part are rounded making alignment very difficult



Rule has sharp corner but part is rounded



Surfaces making up reference point are not square



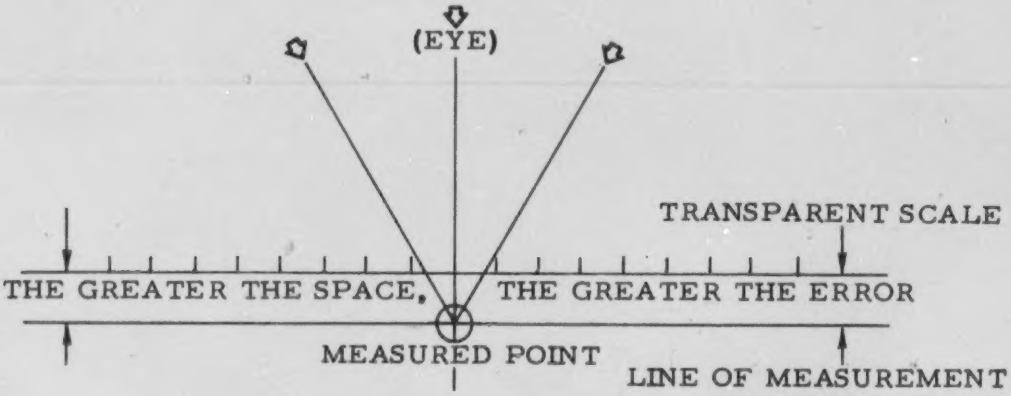
As probably noted, using the end of a rule to establish the starting point is to invite error. Not only may the corners of the rule be worn or rounded - a fact easily confirmed by examination under a magnifying glass - the edge or surface of the part coinciding with the reference point may not be sharp or square. A much more reliable method is to butt the part and rule against a butt plate, knee or similar flat surface. Another is to use a hook rule or hook attachment to establish a firm reference point, or use a scale graduation and ignore the end of the rule altogether.

Therefore, to get any degree of accuracy in performing measurement, the steel rule must be properly aligned with the reference point and the measurements should always be read to the center of graduations.

A significant factor to remember when reading a rule or scale is the degree a unit of length is subdivided. This is called discrimination. It is also the finest division that can be read reliably.

Another form of observational error that must be known is "parallax error"...the apparent shifting of a measurement when viewed from different directions. Parallax occurs when the graduations of a rule are not positioned directly on the line of measurement.

To avoid parallax, the head must be positioned so that line of sight is perpendicular to the line of measurement.

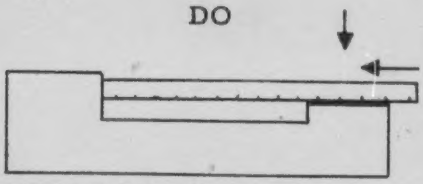


Avoiding manipulative or manual error is also important. This is the error that generally results from using too little or too much force and bending or cocking the rule. It is the error that results from improper handling of the part and rule. The name of the game is to let the rule do the work.

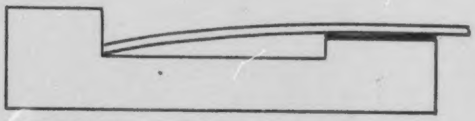
THE RULE SHOULD BE POSITIONED ON THE LINE OF MEASUREMENT AND HELD LIGHTLY BUT FIRMLY.

DO

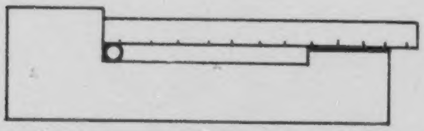
DON'T



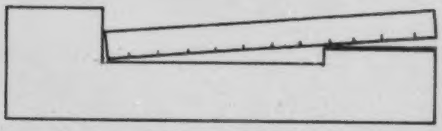
APPLY LIGHT FORCE IN DIRECTION OF ARROWS



BEND OR CRAMP RULE



USE AN AUXILIARY SUPPORT WHEN NECESSARY



COCK RULE

Visual bias is another source of error and is caused by unconscious influencing a measurement. An example is when measuring the diameter of a hole, the blueprint calls for 2 1/4 inches. The rule is positioned over the hole and moved back and forth slightly, using the reference point as the pivot until the longest dimension, the measured point, can be read at the opposite side of the hole.

It is obviously easier to read 2 1/4 inches than 2 15/64 or 2 17/64, particularly when 2 1/4 inches is the dimension we want. So unless some conscious effort is made we tend to read the easier dimension. Add to this the fact that part and rule are subject to slip when moving the eye from the reference point to the measured point, particularly when both the part and rule are held by hand, and we have still another source of possible error.

It is well to remember that repetition is the test of an accurate measurement. If a part is measured several times in the same location and different readings are made, then the measurements are not being taken accurately.

Lack of repetition is a reliable indicator that something is wrong. Either the procedures are at fault or the measuring device itself is defective. A frequent source of error is a bent, loose, or worn rule hook.

In summary, there are several sources of error when using a rule or scale. The most common were reviewed for student awareness. They are:

Improper Alignment
Discrimination
Parallax
Manipulative or Manual
Visual Bias

ACCESSORIES AND USES

There are a number of accessories other than the hook attachment that are used with rules. Some of these are listed with their use in applications:

Key seat clamps - for aligning a rule with the axis of a cylinder.

Parallel clamps - for clamping two or more rules together.

Right angle clamps - for clamping two or more rules together.

Square heads - for measuring and scribing lines normal to a straight edge.

Center heads - for measuring and scribing lines through the center of a circular surface.

Protractor heads - for measuring angles.

Combination square - consists of a steel rule or blade with a sliding square head and scriber.

Combination set - the same as the combination square but has included a center head and a protractor head.

The combination set is probably the most useful of the steel rule variations. It can be used to check squareness and plumb as well as measure height and depth. It can be used to lay out 45- and 90-degree angles. By adding a right angle clamp and another steel rule, it can often be used to measure an otherwise inaccessible point. Substituting the center head in place of the square head, it can be used to find the center of a shaft, etc., or to speed measurement of diameters. Substituting the protractor head provides a convenient means for checking angles.

In using rule accessories and attachments, keep in mind that none of them change the basic principles of the steel rule. They merely add convenience or extend the rule's range of application to jobs which otherwise could not be performed with rules. They make rule measurement easier which in turn generally increases the reliability of measurements.

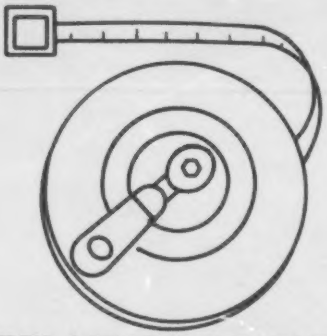
DEPTH GAUGE

This popular variation of the steel rule is the simple depth gauge consisting of a T-head or stock, a screw clamp, and a sliding rod or narrow flat rule. The sliding rods may be plain or graduated. Some versions of the depth gauge use hooked rules for measuring the depth of through holes. Some have heads which pivot with respect to their rules.

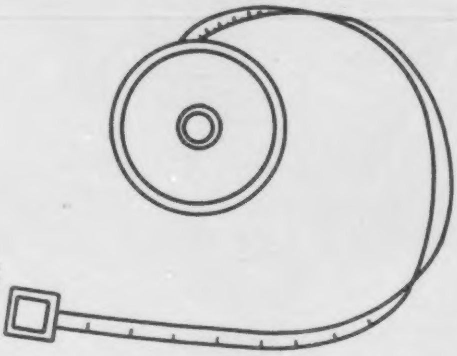
To use the depth gauge, the gauge head is held against the workpiece so that is spans the shoulders of the recess or hole to be measured. The sliding rule or rod is pushed into the hole until it bottoms, and the screw clamp tightened. The gauge is then withdrawn and the rule's scale read. When plain rods are used, the length of the rod protruding from the head is measured with a separate rule.

THE STEEL MEASURING TAPE

The steel measuring tape is an extension of the steel rule consisting of a narrow and fairly flexible strip of tempered steel, marked off in either inches or centimeters, and housed in a protective case. The tape is extended by pulling on the end of the tape and retracted using a small crank on the side of the case. The pocket sizes generally include a spring-driven retraction mechanism which retracts the tape when a small button is pushed.



STEEL MEASURING TAPE



POCKET TAPE

Steel measuring tapes are available in 25, 50, 75, and 100 foot lengths. The pocket tapes come in 6 and 8 foot lengths, although other lengths are not uncommon. Graduations are usually in 8ths of an inch for the standard tapes and in 16ths of an inch for the pocket tapes.

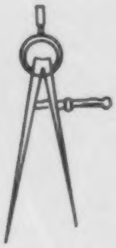
The same basic principles of measurement which apply to steel rules also apply to steel measuring tapes. Like the steel rule, the start of the tape is carefully aligned with the reference point. The tape is stretched along the line of measurement and the measured point is read directly from the tape. In using steel measuring tapes, however, particular attention must be paid to supporting the tape and applying the proper tension. The tape must be held substantially flat and not be allowed to sag. Applied tension should be moderate (10 pounds).

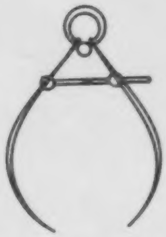
It should also be remembered that steel measuring tapes are sensitive to variations in ambient temperatures. This means that when measuring with steel tapes, consideration must be given to contraction and expansion of the tape.

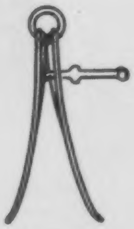
SIMPLE CALIPERS

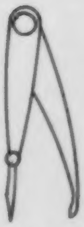
In using steel rules the position of the measured point or edge in relation to scale graduations is judged by sight. Frequently, however, two contact points are necessary to measure a dimension more accurately or to reach surfaces or features otherwise inaccessible. This is where calipers come into the picture.

Calipers are instruments that physically duplicate the separation between two points. The simpler forms, of which we are concerned with here, consist of two legs or points which can be adjusted to duplicate any dimension within their range. They require the use of a separate scale to read the measurement. Below are some examples.

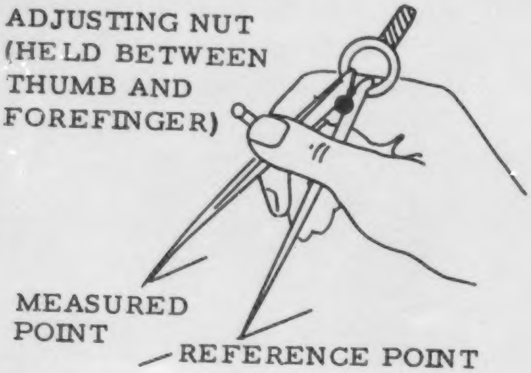

DIVIDER


OUTSIDE
CALIPER

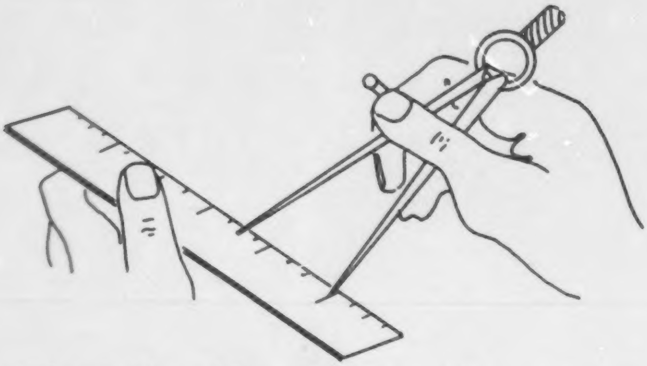

INSIDE
CALIPER


HERMAPHRODITE
CALIPER

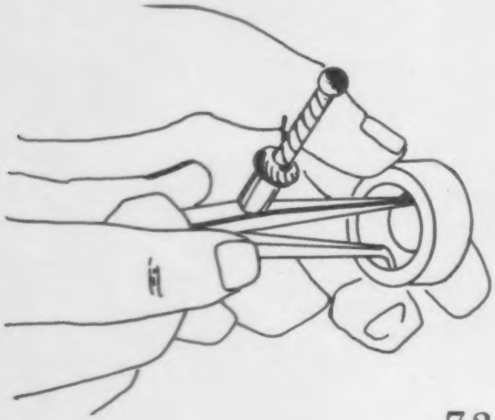
The divider is used to scribe arcs, radii and circles, and to lay out distances set from a rule. It also can be used to transfer distances for measuring with a rule. In transferring a measurement from a part to the scale on a rule, the customary procedure is to locate one point on the reference point, then turn the adjusting nut so that the other point falls exactly on the measured point. When properly set, there should be no pressure tending to spring the points either in or out.

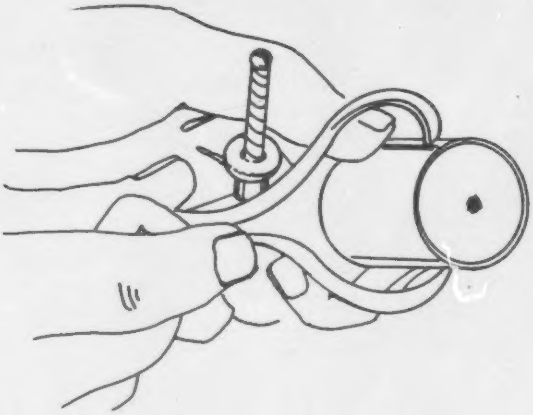


The divider is then placed on a rule with one point in one of the graduations and the scale is read at the other point as shown below.

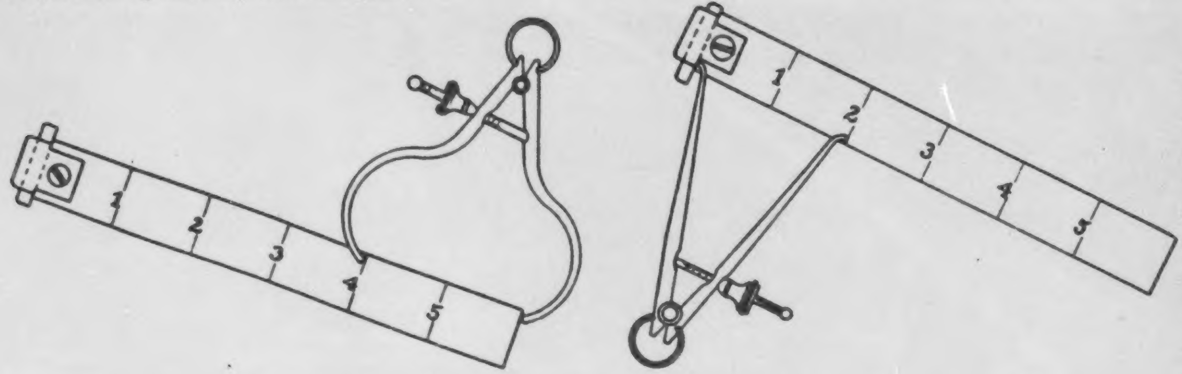


Inside and outside calipers perform the same general function as the divider in transferring measurements except one is used to measure inside surfaces and the other measures outside surfaces.





The caliper is first set to the opening or feature of the part. The separation is then transferred to a rule and read. In reading the inside caliper, the rule and one leg of the caliper are generally butted against a flat surface to provide a stable reference point (below right).



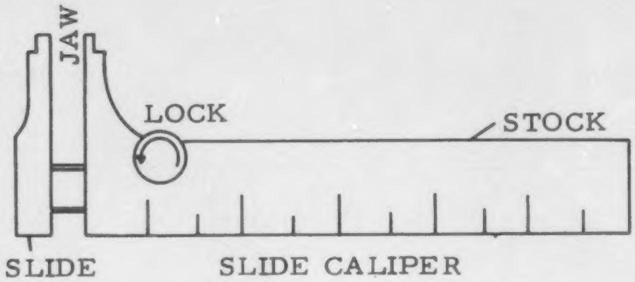
In reading the outside caliper, one leg is positioned in contact with the end of the rule (above left).

Two important factors in taking measurements with inside and outside calipers are caliper alignment and the gauging pressure or force used. In taking measurements, one leg or point should be set as the reference point and the caliper then rocked and adjusted until correct measurement is obtained.

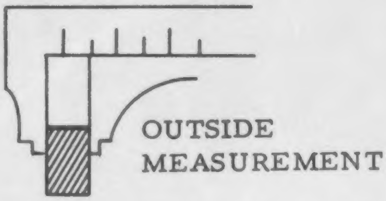
The correct measurement is obtained by the "feel" of the force exerted on the part as the caliper moves over center. Since only a slight force is necessary to spring the caliper legs, the lighter the "feel" is kept the more reliable the measurement.

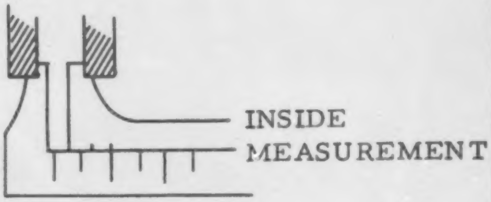
SLIDE CALIPERS

The slide caliper is actually another variation of the steel rule with one fixed jaw and one sliding jaw to permit direct reading of measurements. It comes in a number of sizes with fractional inch, decimal inch, or metric scales. It comes equipped with a slide lock for locking the jaws in any desired position. It includes a "nib" on the tip of each jaw to permit the taking of inside measurements.



SLIDE CALIPER





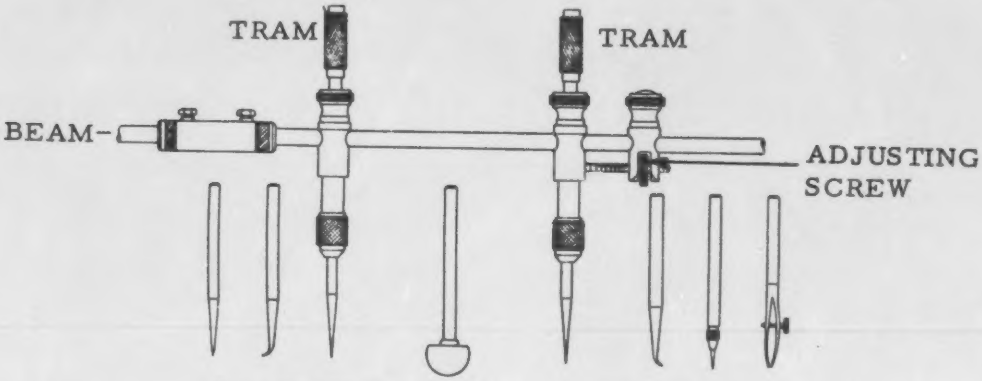
When the jaws are brought in contact with surfaces being measured, the distance between them may be read from the scale.

An advantage in using a slide caliper over the steel rule is that the slide caliper provides positive contact between instrument and the reference and measured points.

BEAM TRAMMELS

The beam trammel is simply a divider with extended range. It consists of a rod or beam to which trams may be clamped. The trams in turn carry chucks for inserting divider points, or caliper points. Its use is confined chiefly to measurements beyond the range of dividers and calipers.

Below you will notice one of the trams is equipped with an adjusting screw to provide fine adjustments.



BEAM TRAMMEL AND ATTACHMENTS

A summary of what has been presented in this chapter is as follows:

1. A "scale" is a graduated surface for decreasing or increasing a unit of length.
2. The "rule" is a direct measuring device graduated in actual units in length. It may carry fractional inch, decimal inch, or metric scales.
3. The scales used should agree with the dimensioning of the part or object to be measured. That is, use fractional inch scales for franctional inch parts, decimal inch scales for decimal inch parts, and metric scales for metric parts.
4. "Reference point" is the term used to identify the start of a measurement.

5. 'Measured point" identifies the end of a measurement.

6. The "line of measurement" is a straight line drawn between and and intersecting the reference point and measured point.

7. "Discrimination" refers to the degree a scale subdivides a unit of length. It is also the finest division that can be read reliably.

8. Rules are read to the center of graduations.

9. The measured point is read to the nearest graduation.

10. To use the end of a rule to align rule with reference point is to invite error.

11. "Parallax error" is the apparent shifting of a measurement when viewed from different directions.

12. 'Manipulative or manual error" is the error that results from using too little or too much force and not positioning the rule properly.

13. 'Visual bias" is the unconscious influencing of a measurement.

14. The same basic principles of measurement which apply to steel rules apply to all the scaled instruments and their accessories.

15. Instruments are selected on the basis of which one will best do the job.

16. Accessories and attachments add errors. Use should be confined to measurements in which the added convenience, or their application, increases the reliability of a measurement more than they decrease it.

17. Every transfer of measurement adds steps and added steps add errors...a factor that should be considered in using transfer instruments such as the caliper.

18. Transfer instruments depend on the "feel" of the user for accuracy.

19. In using steel measuring tapes, one should also consider the effects of changes in ambient temperature on measurements.

20. It is good practice to repeat measurements until satisfied as to their accuracy...write down measurements rather than trust them to memory...use mechanical support as opposed to hand support whenever possible... ensure both part and the measuring device are clean before taking measurement.

STUDENT ACTIVITIES

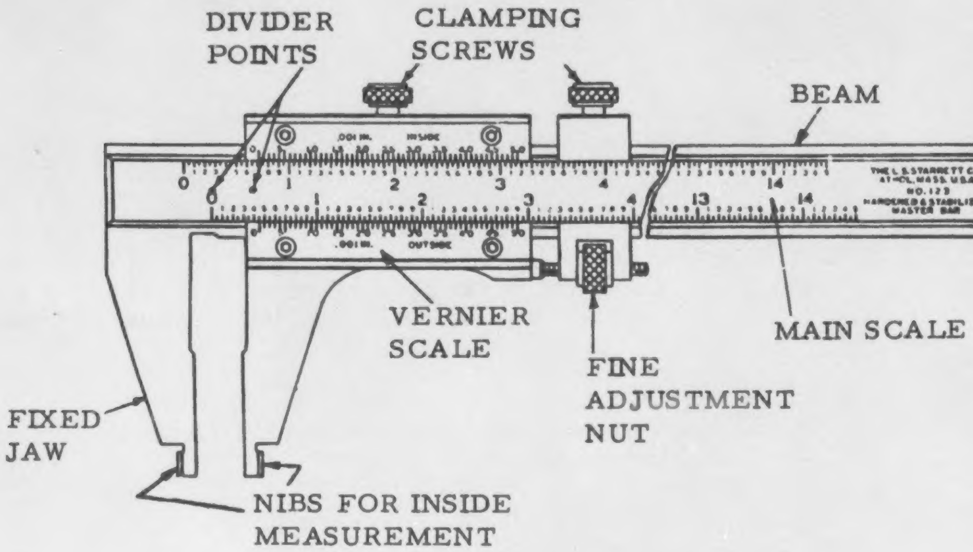
1. Review and ensure personal knowledge of the various rules and gauges.
2. Obtain a steel scale, measuring tape and accessories from the home workshop, or school metal shop and practice measuring various items. Awareness should be made of the types of errors described in the resource guide. Attempt to duplicate parallax, discrimination, measured point, and manipulative errors.
3. Using a 10 foot rule, measure the height of students in your class. Make a comparison of these measurements with the metric conversions.
4. Using a 2 foot rule measure pre-cut stock. The length of stock should be cut to various lengths and include fractions which correspond to graduations of the rule.
5. Using a 6' wood rule or metal tape, measure a classroom. Then use a 50 or 100 foot measuring tape and compare the results.
6. With a steel rule measure various lengths of metal stock in the metal shop. Measure in various fraction accuracy, such as 1/8", 1/16", 1/32", and 1/64".
7. Visit the metal shop and ask the teacher to show you the various types of steel rules, accessories, and calipers. Perhaps the teacher will demonstrate the uses for you.

VERNIER INSTRUMENTS

Vernier hand measuring devices are very essential to the entry level industrial manufacturing employee. Therefore, an in-depth review is made to familiarize the student with the basic requirements.

THE VERNIER CALIPER

The vernier caliper is essentially a slide caliper that incorporates a vernier scale and a fine adjustment.

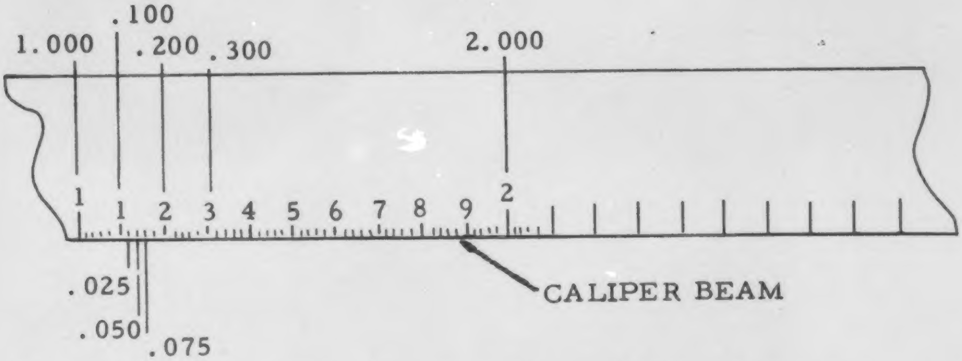


The typical instrument consists of an L-shaped frame or beam, the end of which forms the fixed jaw, and a sliding jaw assembly made up of two sections joined by a screw and adjustment nut. The vernier scale attaches to the sliding jaw and moves parallel to a main scale engraved on the caliper beam. Design is such that readings are made from one scale to the other with minimum parallax error. Two center points are usually provided on the side of the instrument for setting dividers to close dimensions. The "nibs" for inside measurement are ground to a radius to permit single-point contact with small holes and bores. A variation of the vernier caliper uses knife-edged jaws for gauging surfaces.

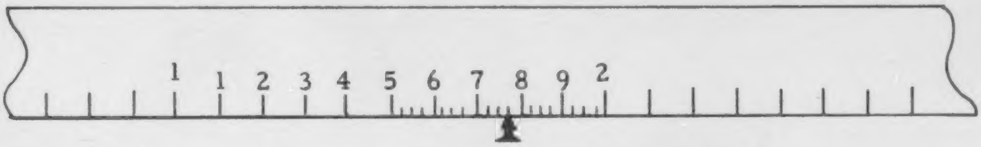
The vernier and main scales on one side of the instrument generally read outside measurements while the scales on the opposite side read inside measurements. Sometimes both the inside and outside scales are found on the same side of the instrument, one above the other.

READING VERNIER SCALES

First consider the standard 25-division vernier. The main scale itself is graduated in full inches. Each inch is divided into ten parts and each of the tenths is again subdivided into quarters.



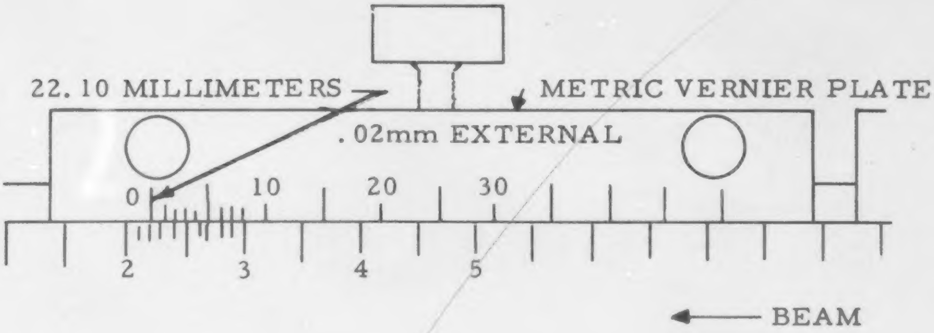
(The scale is read by adding the inches, tenths and quarters together.)



The reading of the above scale is therefore 1.775.

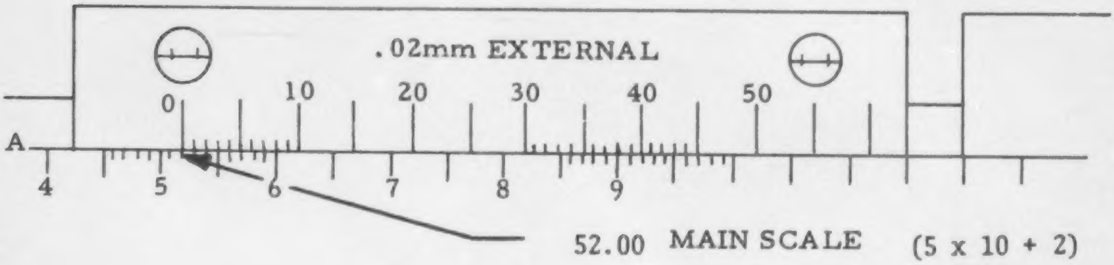
The vernier scale contains 25 divisions in the same length that the main scale has 24. Each vernier division is 1/25th smaller than its main scale counterpart. Since each main scale division equals 1/40th of an inch (.025 inch), this means each vernier division equals 1/25th of 1/40th of an inch or 1/1000th of an inch (.001 inch).

There are also metric vernier calipers.



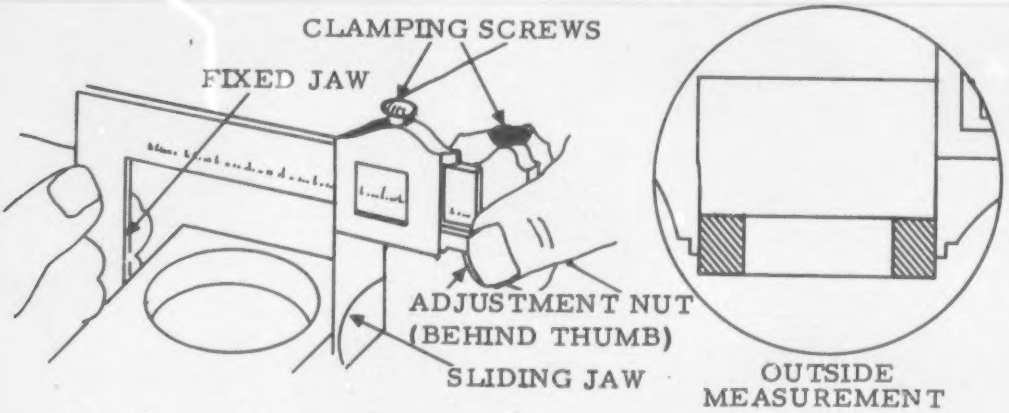
Using the vernier "O" line as the index, the above metric scale reads 20 + 2 beam graduations, or 22 millimeters, plus the vernier reading of the line which coincides with beam line. In the example, that line is "5". Thus 22 millimeters (the beam scale reading) + 5 X .02 (the vernier scale reading) equals 22.10 millimeters...the sum of the beam and vernier scales.

An example of reading a metric scale is:



MEASURING WITH VERNIER CALIPERS

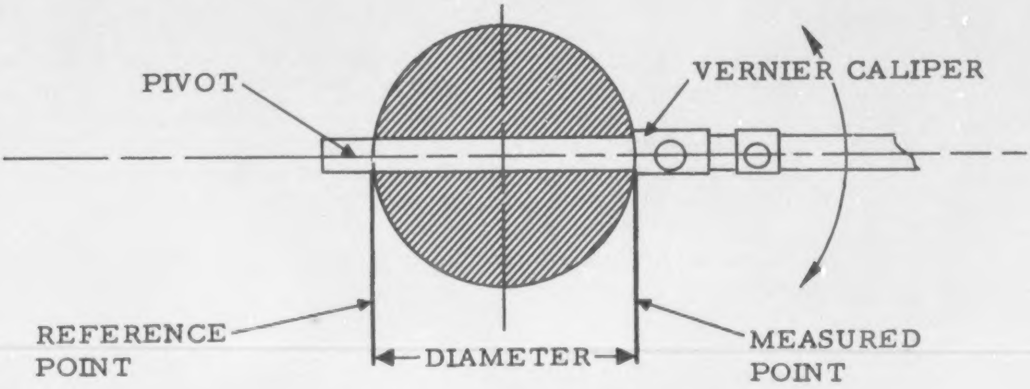
In taking outside or exterior measurements, the caliper jaws are set slightly larger than the distance to be measured and the adjustment nut carrier locked to the beam by tightening the appropriate clamping screw. The sliding jaw clamping screw is in turn snugged up but not so tight as to lock the jaw.



The caliper is then gripped near or opposite the jaws - one hand at the fixed jaw and the other generally supporting the sliding jaw - and the caliper carefully positioned on the part or feature to be measured. With the fixed jaw held against the reference point and the axis of the instrument parallel and in plane with the line of measurement, the sliding jaw is moved using the fine adjustment nut until it just contacts the measured point. The sliding jaw is locked by tightening the appropriate clamping screw and the "feel" between the caliper and part rechecked. The student should remember that "feel" refers to the gauging pressure or force used in setting the instrument to measure a part dimension or feature.

Inside or interior measurements are performed in essentially the same manner except at start of measurement, the jaws are set slightly smaller than distance to be measured, and the measurement is read from the scales marked "INSIDE" or "INTERIOR."

In measuring a diameter, the procedure is to hold the fixed jaw against the reference point and swing the sliding jaw back and forth past center while turning the fine adjustment nut. Correct setting is obtained when the sliding jaw just contacts the measured point as it passes center.



In measuring the vernier calipers, whether it is an outside measurement, an inside measurement, or the measurement of a diameter, it is the fixed jaw that is always used as the reference point.

SOURCES OF ERROR

A basic law of measurement states that maximum accuracy is obtainable only when the axis of the instrument lies on the same line as the line of measurement. Because caliper jaws are offset from the axis of the instrument, alignment therefore becomes a very important consideration when measuring with vernier calipers.

In taking measurements, always make sure the caliper beam and the plane of the jaws are truly perpendicular to the surfaces being measured. Other important factors are:

1. Never allow the instrument to tip, twist or become canted. In other words, greatest accuracy is obtained when the axis of the instrument is held parallel and in plane with line of measurement.

2. Centralizing - rocking the instrument slightly on the reference point and the sliding jaw adjusted until the measured point falls on the true diameter. The procedure is to hold the fixed jaw against the reference point, move the sliding jaw in a small circle, and at the same time turn the adjustment nut until contact is felt. The sliding jaw is then backed off slightly and the process repeated using smaller and smaller circles until the caliper jaws rest squarely on the reference and measured points.

3. Another source of error is the use of excessive gauging pressure. Over-tightening in fact can not only result in inaccurate and unreliable measurements, it could burnish the part...it could even damage the instrument. Correct gauging pressure is obtained when contact between part and caliper jaws can just be felt.

4. Lack of magnification can also lead to discrimination error.

5. In obtaining accurate and reliable measurements, it is required that both the part and measuring device are clean. Surfaces should be wiped free of any dirt, grit, or oil. Along the same line, you should make certain there are no burrs or other obstructions which could affect measurement.

6. As in measuring with steel rules, it is a good practice to write down a measurement rather than trust it to memory. It is good practice to repeat a measurement until satisfied as to accuracy.

CARE OF VERNIER CALIPERS

A primary consideration in the care of vernier calipers is the condition of the jaws. For example, they may become bent or sprung. They are also vulnerable to wear. Some of the common wear patterns are:

Wear from measuring outside diameters.
Wear from general use.

Wear from measuring inside diameters.
Sliding jaw-fame wear and warpage.

The calipers could be easily checked for these wear patterns by closing the calipers tightly and hold them up to the light and sighting through the crack. If light can be seen, it means some degree of wear exists. When wear does exist and it exceeds .0002 inch, the instrument should be returned to a gauge maker or the calibration laboratory for reconditioning.

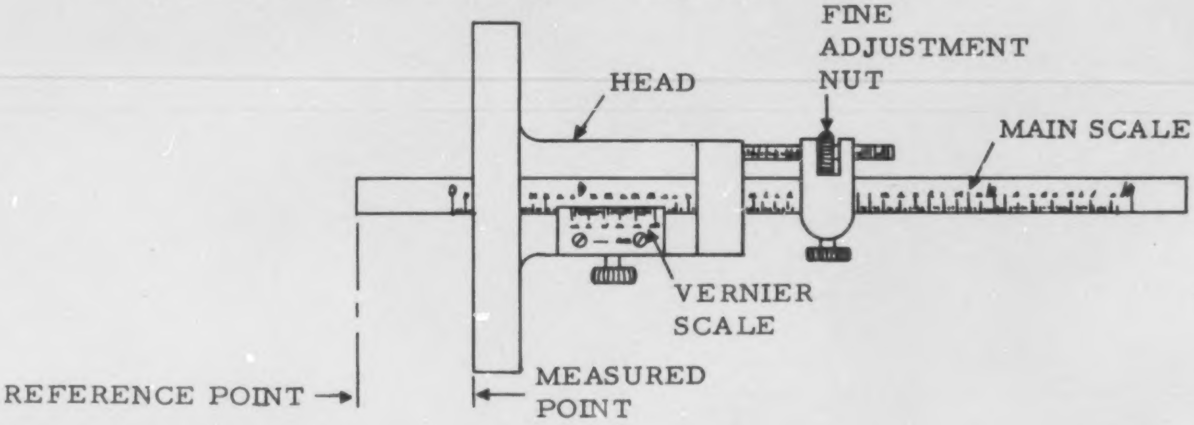
Zero setting - is checked by closing the caliper and observing if the vernier reads zero. If not, it can be adjusted by loosening the vernier plate screws and respositioning the scale.

Precautionary Note: The accuracy and reliability of the vernier caliper depends on how much care it receives. Some very basic hints on maintenance are:

Handle the instrument gently
Keep free of dirt, and grit.
Keep in appropriate box when not in use.
Never use the vernier caliper as a wrench
hammer or pry bar.

VERNIER DEPTH GAUGES

The vernier depth gauge is essentially a rule depth gauge incorporating a vernier scale and fine adjustment.



To use the instrument, the head or base is generally rested on or against the reference point and the graduated beam adjusted to contact the measured point. Reading of the scales is identical to the vernier caliper.

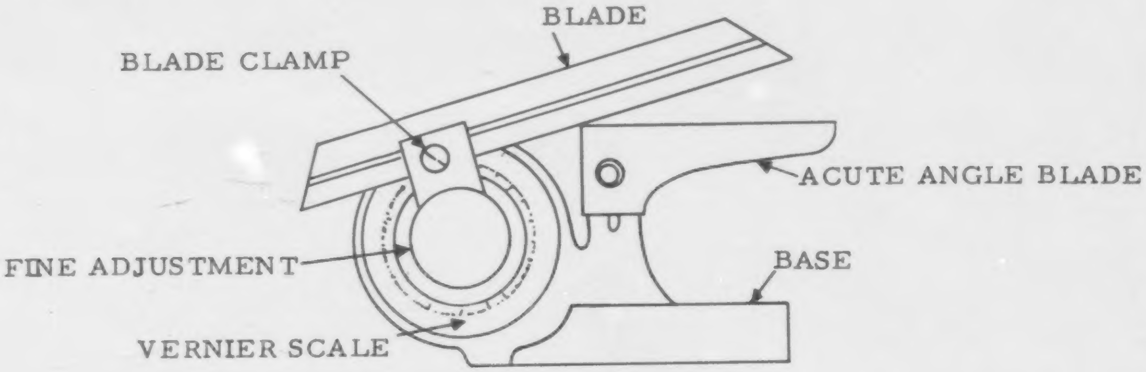
Like the vernier caliper, the vernier depth gauge is subject to a number of manipulative errors. In fact, it is probably easier to make manipulative errors with a vernier depth gauge than any other measuring device. Some of the errors associated with the use of vernier depth gauges are:

Part features not square or true.
Base lifted from reference point.
Base tilted.
Manipulative errors.

Therefore, a firm pressure must be maintained in holding the base against the reference point, while at the same time using a very light touch to set the graduated beam against the measured point.

UNIVERSAL BEVEL PROTRACTORS

The universal bevel protractor, also called a bevel protractor or vernier protractor, is a precision angle-measuring instrument designed for layout and checking of angles. It consists of a base and a blade which can be revolved in relation to each other and set in any desired position. An acute angle attachment permits a longer line of contact in measuring small angles. Below is a typical bevel protractor.



STUDENT ACTIVITIES

1. Visit the metal shop and ask the teacher to demonstrate the various vernier measuring instruments. Perhaps you will be able to practice taking some actual measurements.

2. Review the differences in reading the regular scales and the metric scales if they are available.

3. For the student or entry-level employee, effort should be made to learn the care and handling of the vernier measuring instruments.

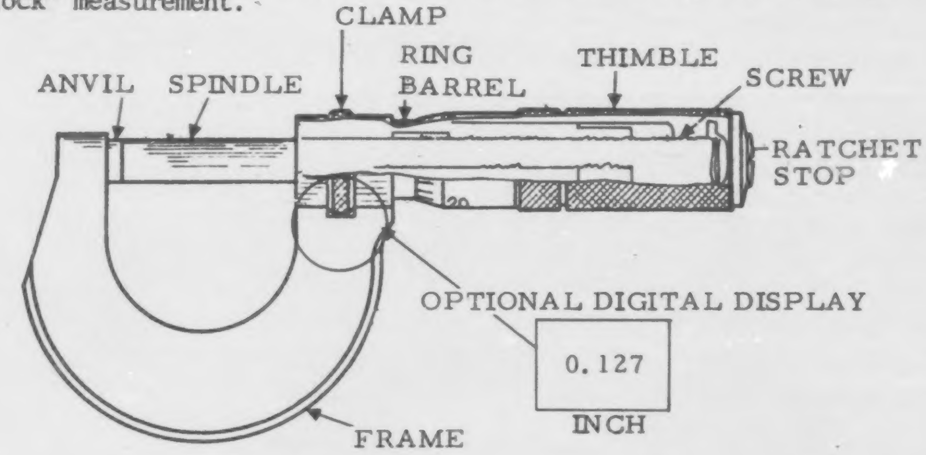
4. The student should remember that there is only one way to become proficient in using delicate and precise measuring instruments, this is with practice. Considering this, the student should expend all available time in getting the "feel" of the instruments.

MICROMETER INSTRUMENTS

Micrometer instruments achieve even greater precision than the vernier instruments by using a finely threaded screw to amplify readings. There are many types of micrometers. The most commonly used are:

Outside micrometer calipers
Inside micrometer calipers
Micrometer depth gauges

The most general reference to the term micrometer is the outside micrometer caliper. The basic components of the outside micrometer caliper include a frame, anvil, spindle, barrel, and thimble. Many have a ratchet stop to help establish the proper "feel" or torque when making measurements. Many have a clamp ring to "lock" measurement.

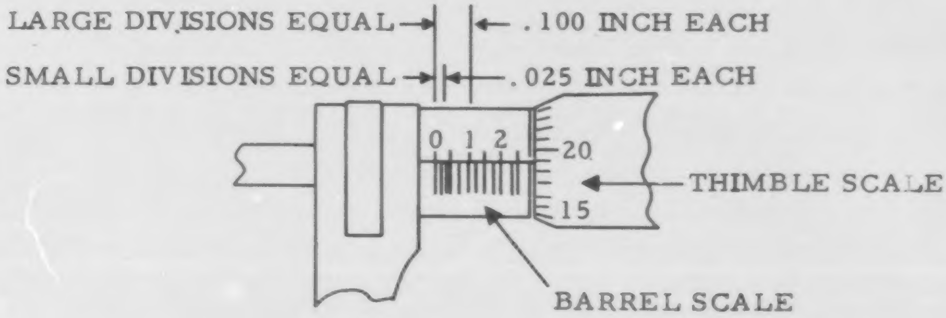


Micrometer screw, which is actually a part of the spindle, threads through a stationary nut located within the barrel. The thimble attaches to the spindle and acts as a dust cover. A linear scale is provided on the barrel to measure the axial movement of the spindle. A circumferential scale on the thimble indicates the amount of partial rotation of the thimble. Some micrometers include a vernier scale on the barrel for measuring in still finer increments of thimble rotation. Some include a digital display for faster and easier reading. The part of the micrometer that moves back and forth with thimble rotation is the spindle. The anvil represents the fixed reference point of a micrometer measurement.

In addition to different types of micrometers, there are different sizes. The designated size of a micrometer being its largest opening - not its range. For example, the 1-inch micrometer has a measurement range of 0 to 1 inch; the 25-millimeter metric micrometer measures from 0 to 25 millimeters. Larger "inch" sizes are designated 2 inch, 3 inch, 4 inch, 5 inch, while metric sizes run 25, 50, 75, and 100 millimeters. Regardless of micrometer size, however, the range of measurement is usually limited to 1 inch for inch micrometers and 25 millimeters for metric micrometers. This means that a 6-inch micrometer can be used for measuring dimensions of 5 to 6 inches only.

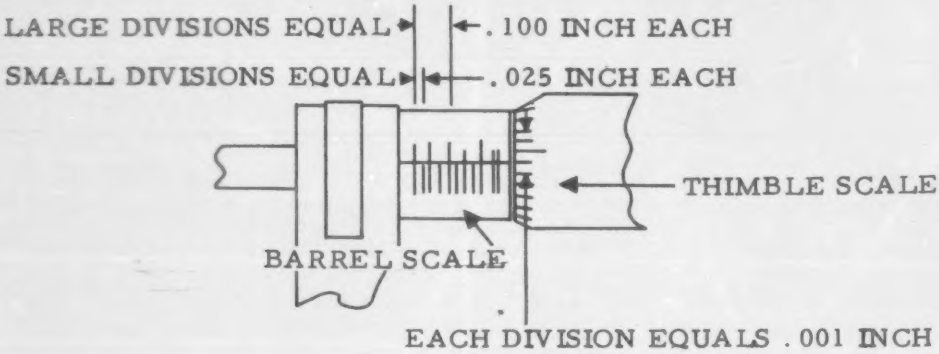
READING THE "INCH" MICROMETER

Reading a micrometer is simply a matter of counting the revolutions of the thimble and adding to this any fraction of a revolution shown on the thimble scale. The pitch of the "inch" micrometer screw is usually 40 threads per inch. This means that each complete turn of the thimble moves the spindle 1/40 or .025 inch. The barrel scale is in turn graduated so that each division represents one revolution of the thimble or .025 inch.



From 0 to 1 on the barrel scale are four divisions, so that "1" on the scale represents 4 x .025 or .100 inch; "2" is equivalent to .200 inch; and "3" to .300 inch.

If "3" on the barrel scale is equivalent to .300 inch, "5" on the scale represents 5 x .025 or .125 inch. The barrel scale shown below reads .200 + .025 x 3 (the number of divisions showing to the right of .200) or .275 inch + a part of a division.

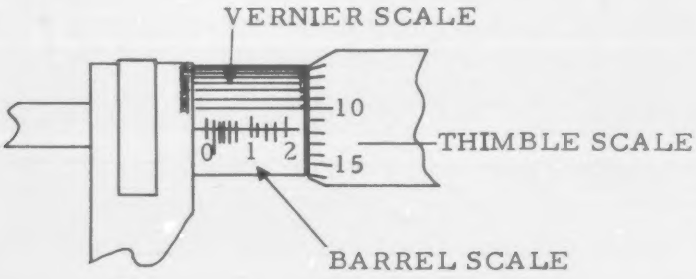

LARGE DIVISIONS EQUAL .100 INCH EACH
SMALL DIVISIONS EQUAL .025 INCH EACH
THIMBLE SCALE
BARREL SCALE
EACH DIVISION EQUALS .001 INCH

The thimble scale has 25 divisions, each division representing 1/25 x .025 or .001 inch. Using the horizontal line on the barrel scale as the index, note that the part of a revolution indicated on the thimble scale above is 19, meaning 19 x .001 or .019 inch. Adding this value to the whole divisions showing on the barrel, we have the measured distance.

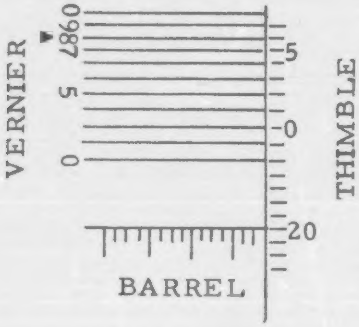
```
  .275 (reading from barrel scale)
+ .019 (reading from thimble scale)
  .294 (measured distance)
```

THE VERNIER MICROMETER

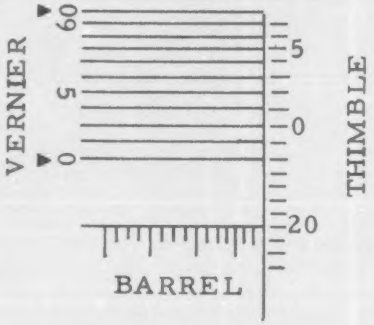
These are micrometers that include a vernier scale on the micrometer barrel for carrying a measurement to four places (.0000).



The vernier scale consists of 11 equally spaced lines. The first ten are numbered zero through nine, with the eleventh line identified as another zero. The vernier is read by matching a vernier graduation to a thimble graduation, noting the vernier number and adding this number as the fourth digit. Shown below are two examples.



.2698 INCH



.2700 INCH

Notice that when micrometer reads in whole thousandths, both zeros on the vernier scale match up with thimble lines.

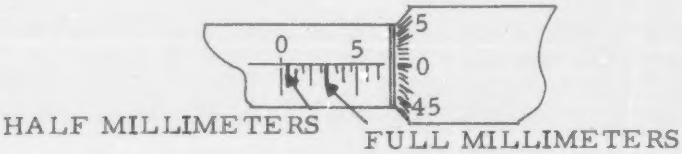
SOURCES OF ERROR

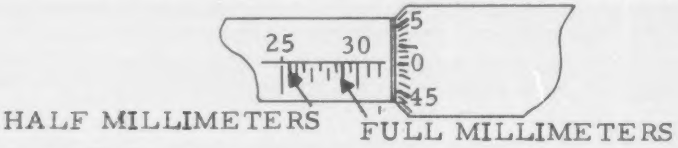
The following are possibly the most common sources of error in reading micrometer scales:

> Barrel scales are frequently misread an additional .025 inch.
>
> The thimble is read in the wrong direction.

READING THE "METRIC" MICROMETER

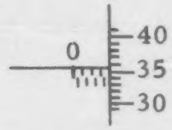
With metric micrometers, several variations of the barrel scale are used. Below are two typical examples.



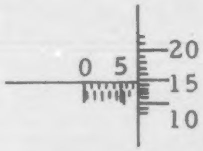


Each complete turn of the thimble moves the spindle 1/2 millimeter (.5mm). Two turns equal 1 millimeter (1mm). The thimble scale in turn has 50 divisions dividing the 1/2 millimeter graduations of the barrel scale into hundredths of a millimeter (.01 mm). To read the metric micrometer, first count the "full" or whole millimeter graduations. Add the next 1/2 millimeter graduation if visible, plus the thimble reading.

A



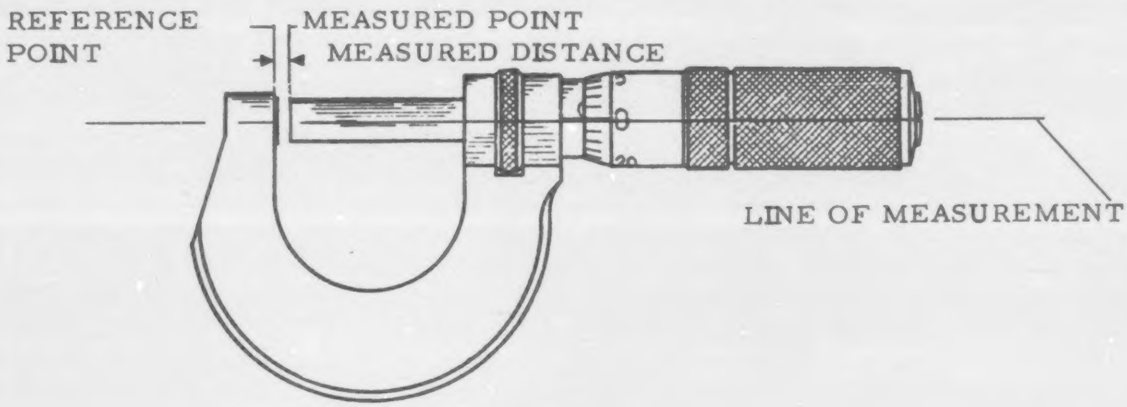
B



Whole mm Lines Visible on Barrel	3 = 3.00mm	7 = 7.00mm
Additional 1/2 mm Visible on Barrel	1 = .50mm	0 = .00mm
Thimble Reading	36 = .36mm	15 = .15mm
Measured Distance	3.86mm	7.15mm

USING THE MICROMETER

The basic principles of measurement with micrometers are essentially the same as for the instruments already discussed. Specifically, measurement with a micrometer involves a reference point, measured point, and a line of measurement.



The most common application of micrometers is the measurement of length dimensions between two parallel end surfaces on the outside of an object or feature. The micrometer is set to duplicate the separation between reference point and measured point, with the axis of the instrument on the line of measurement.

The part or object is held in the left hand while the right hand holds the micrometer so that the thimble can be turned between the thumb and combined index and third fingers. The fourth and fifth fingers are used to clamp the frame against the palm of the hand. A drawback of this method is that in most instances the fingers are too short to reach the ratchet stop.

A more reliable method is to use a bench stand or equivalent device to support the micrometer thus leaving the hands free to concentrate on measurement. The ratchet stop is also accessible.

On larger and bulkier work, different methods of holding the micrometer are used. One hand is generally used to hold and align the micrometer while the other hand is free to turn the thimble either directly or using the ratchet stop.

The micrometer is first set to an opening slightly larger than the distance to be measured. This is easily and quickly done by rolling the thimble along your hand or arm. Never change the setting by grasping the micrometer by the thimble and twirling the frame. To do so only accelerates threadwear. It could also damage the micrometer should the spindle be jammed into the anvil.

In gauging flat surfaces, the micrometer is placed on the work and the anvil positioned squarely against the reference plane. (A feeling of stability usually occurs when the axis of the micrometer is perpendicular to the reference plane.)

The spindle is then closed on the measured plane by slowly turning the ratchet stop until it releases one click. The measurement is read. The purpose of the ratchet stop is to control the torque applied to the spindle thereby ensuring a more uniform measuring force.

Very small diameters are gauged in much the same manner as flat surfaces. For larger cylindrical parts, however, a different method must be used in aligning the micrometer with the line of measurement.

In measuring large diameters it is necessary to "feel" the setting to be sure the spindle is on the diameter. This is accomplished by rocking the micrometer back and forth over center while closing the micrometer by small steps. When contact is felt, the micrometer is then rocked sideways slightly to find the position of last contact. The rocking back and forth and sideways is repeated until the perpendicular position is found and the spindle just contacts the measured point as it passes over center. The measurement is then read from the micrometer barrel and thimble scales.

In other words, cylindrical surfaces are measured by rocking the micrometer over center and turning the thimble in very small increments until the spindle just contacts the diameter. Flat surfaces are measured by placing the micrometer anvil squarely against the part and using the ratchet stop to set measuring pressure.

Another point to keep in mind is that even though many micrometers read to .0001 inch, their structural design is not sufficiently rigid for reliable measurement to .0001 inch. Generally speaking, don't expect to measure with any accuracy to closer than .0002 inch.

CARE OF MICROMETERS

1. Dirt not only causes rapid wear but buildup on measuring surfaces can create errors of as much as several thousandths of an inch. This means that before a micrometer is used it should be wiped free of oil, dirt, dust, and grit. A popular method of cleaning the measuring surfaces of the 1-inch micrometer caliper is to close the micrometer lightly but firmly on a piece of soft paper, then withdraw the paper. The spindle is then opened a few turns and any remaining fuzz or dust is blown away.

2. A micrometer may also become gummy and the thimble fail to turn freely. This requires disassembly and washing of the micrometer components in a suitable cleaning solvent, then relubricating with a light oil and assembling the parts. Just soaking the assembled micrometer will only transfer the dirt to another part of the micrometer and perhaps make it even more difficult to clean. It also washes away needed lubrication. Furthermore, the apparent sticking may not be due to gum and grit at all but to a damaged thread or a sprung frame or bent spindle. In checking the micrometer, the spindle should turn freely with no play at any point in its travel. Any adjustment or repair should be done according to the manufacturer's instructions.

3. Perspiration as well as cutting oils are highly corrosive to the finely finished surfaces of a micrometer. At the end of the work day, the micrometer should be wiped clean and lightly oiled before it is returned to its case. Oiling of micrometer surfaces is highly essential for protection against rust and corrosion.

4. Never leave a 1-inch micrometer with the spindle in contact with the anvil or leave any micrometer tightened on its standard. (The finely finished contact surfaces corrode quite rapidly when left "wrung" together, probably because of electrolytic action.)

5. Never use force or cramp the micrometer to make it fit because it can be sprung or bent.

6. Never overtighten a micrometer or use it as a snap gauge.

7. Some typical cautions are listed below for additional student clarity:

DO	DO NOT
Keep micrometer clean	Twirl micrometer frame
Take care in aligning micro meter with part	Force or cramp micrometer
Use uniform gauging pressure	Overtighten micrometer
Avoid tendency to make micrometer fit	Use micrometer as a snap gauge

Some other major points for the micrometer user to remember are:

1. A check of zero setting will often alert the user to errors in micrometer readings. The check involves closing the micrometer using the same gauging pressure that would be used in making measurements, then observing if micrometer reads zero. Any difference, depending on the direction of error, should be added or substracted from measurements or the micrometer reset according to the manufacturer's instructions.

2. The contact surfaces of a micrometer should be checked periodically for parallelism and flatness. This is readily accomplished using a precision ball to "explore" the contact surfaces. The ball is simply moved from location to location around the contact surfaces and measurements taken of ball diameter. Any deviation in parallelism appears as a change in reading.

3. The contact surfaces of a micrometer could also be checked with an optical flat. The optical flat has the advantage of readily and accurately detecting combinations of wear such as waviness and humps as well as lack of parallelism appears as a change in reading.

4. Micrometers should be checked periodically to verify their accuracy. Calibration usually consists of measuring a selected group of precision gauge blocks and noting any variations from true dimensions.

5. "Standards" are also purchased and/or furnished with micrometers for checking calibration. For 1- and 2-inch micrometers, the standard is usually a disc. For larger micrometers, they are rods. In measuring gauge blocks and standards, the gauging pressure used should be the same as that used in measuring.

VARIATIONS OF THE OUTSIDE MICROMETER CALIPER

Some of the more common variations of the outside micrometer are listed for student and user information. They are:

Disc micrometers - for measuring closely spaced sections.

Blade micrometers - for measuring to the bottom of narrow grooves.

Thread micrometers - for measuring pitch diameters.

Round anvil micrometer - for measuring tubing wall thickness.

Micrometer with interchangeable anvils - to cover a wide range of sizes.

Bench micrometer - for reliably measuring small parts. (The stable position of this micrometer permits a more precise locating of a workpiece and the heavy base adds to the rigidity of the instrument.) Bench micrometers also have a larger diameter spindle and thimble, thus permitting a finer pitch thread for greater sensitivity and direct reading in tenths of thousandths of an inch.

Variations of the outside micrometer caliper are generally according to their anvil configuration. This configuration generally serves as the means of identification excepting the bench micrometer.

INSIDE MICROMETER CALIPERS

The inside micrometer caliper is essentially an outside micrometer caliper with fixed and movable jaws substituted in place of the frame and anvils. Available in three sizes, the smallest dimension that can be measured is .200 inch. The largest is 2 inches.

Designed specifically for inside measurement, the "nibs" or jaw gauging surfaces are ground to a small radius to ensure single point contact. Besides using jaws for gauging surfaces, the inside micrometer is common with the vernier caliper in that both have the instrument axis offset from the line of measurement. Therefore, the same rules regarding rocking and centralizing apply to both instruments.

The inside micrometer has two different scale arrangements. One has the linear scale located on the spindle, while the other has the scale on the barrel. In reading the barrel scale, however, only the covered graduations are read left to right in the conventional manner.

INSIDE MICROMETERS

The inside micrometer generally comes as a set consisting of a micrometer head, handle, spacing collar, and a number of extension rods. The rods are made in different lengths, usually in 1-inch steps, and are assembled to the head by means of a threaded connection or chuck. The smaller heads have a screw travel of 1/2 inch, and the rods are attached either directly or by using the 1/2-inch spacing collar. The handle can be attached to the head to permit measuring at greater depths. A typical inside micrometer set includes the following items:

Handle
Micrometer head
Spacing collar
2 to 3 inch rod
3 to 4 inch rod
4 to 5 inch rod
5 to 6 inch rod
6 to 7 inch rod

The smallest bore which can be measured is generally 2 inches while the largest diameter depends on the extension rod used, the practical limit being about 32 inches. The gauging surfaces or contacts are spherical to permit measuring holes, bores, etc., at their true diameter.

In measuring an inside diameter, the spindle or extension rod is generally held against the reference point and the instrument centralized until contact points rest squarely on the reference and measured points, with axis of the instrument on line of measurement.

Sources of error - in addition to the usual measurement precautions, there are two other possible sources of error when using an inside micrometer. They are:

1. Make sure extension rods are properly seated and locked in their sockets before performing measurement.

2. Do not handle the extension rods unnecessarily. Warming from handling too long can substantially increase their length and thus produce errors.

STUDENT ACTIVITIES

1. The same activities pertain to the micrometer instruments as with other instruments except that perhaps more care must be taken when using them.

2. Visit the metal shop in your school and ask the teacher to demonstrate the micrometer instruments.

3. Perhaps you may enroll in a basic mechanical measurements class and get first hand knowledge of the instrument through actual use.

4. For the entry-level manufacturing industry employee, the basic tools such as the steel rule, vernier caliper, and one-inch micrometer should be purchased as personal tools. Once purchased, read all directions carefully and then practice using the tools on objects in the home or shop.

5. Once the basic tools are fully understood, then the use of the less common micrometers could be learned.

LIMIT GAUGES

Limit gauges (gages) provide a fast economical way to check for tolerance limits and makes possible quantity production. Mass production would be seriously hampered if it was necessary to measure all parts with adjustable tools.

Basically limit gauges are made to measure a single dimension. Some of the most common of these are presented for student/ entry-level employees familiarity:

PLUG GAUGES

These are called go/no-go gauges for the fast inspection of holes, inside diameters, and slots. They are available in single ended models and are ordinarily used in pairs held by hexagonal handles. Types of plug gauges are:

Single ended go
Single ended go for deep bores
No-go
Go/no-go double ended combination
Progressive go/no-go

Descriptive terms for securing gauging members to the handle are:

1. Taperlock - taper shanks fitted into tapered receptable that are limited to smaller diameters through 1.510 inches.

2. Reversible - held by color coded locking nuts, green for go and red for no-go. (May be withdrawn from handle when worn and reversed to present a fresh gaging surface.) It is restricted to 0.760 inches or less.

3. Trilock - three prongs on the handle are forced into corresponding groves of the gaging members by means of a screw passing through the center of the plug and threading into the handle. It is for diameter measurements of 1.510 inches to 8.010 inches.

4. Annular - a wheel type, single ended unit with removable screw-in handles to facilitate the gaging process.

RING GAUGES

These gauges have a bore of known dimensional accuracy with which cylindrical male test pieces may be compared. Also used for outside diameters, thickness, and lengths.

Go-Gauge - represents the maximum tolerance.

No-Go Gauge - represents the minimum tolerance. For identification the no-go is supplied with an annular groove or ring in the knurled periphery. For rings less than or equal to 1.510 inches the gauges are made of solid cylindrical stock. For larger sizes, the gauges are flanged.

MASTER SETTING DISKS

Widely employed for setting and checking micrometers, adjustable snap gauges and all types of comparators whenever a cylindrical test piece is to be compared.

These disks are cylindrical in shape to resemble the part to be checked.

Have insulating grips to help avoid handling the measuring surface.

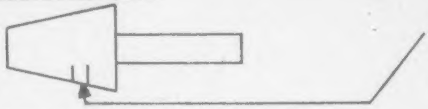
SNAP GAUGES

The group of fixed or slightly adjustable calipers used for the size control of external dimensions. They are also used for thickness and lengths.

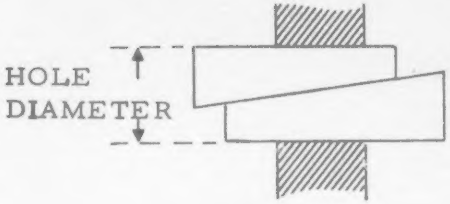
Go/No-go
Double ended combinations on a common frame
Progressive types

TAPER GAUGES - TAPERED PARALLELS

- Taper Gauge - Have two marks on the taper. (If taper enters hole to a point where it stops between marks, the taper is acceptable.)



- Tapered Parallel - Using two tapered surfaces facing each other and placed in a hole. The external edges are gauged to give the hole diameter.



OTHER GAUGE TYPES

Feeler Gauges - blades of various thicknesses.

Radius Gauges - a series of thin steel leaves used as templates.

Fillet Gauges - a series of thin steel leaves used as templates.

Flush Pin Gauges - single purpose gauges designed for the control of a particular dimension on a particular dimension with a particular component.

There are some cautions to be taken when using limit gauges. They are:

Do not force gauges.
For close tolerances, keep part and gauge moving or they may freeze up.
Lubricate when tolerances are close.

Conditions that are difficult to detect with limit gauges are: (when size differences are small):

Ovality
Taper
Bell-mouth
Hour-glass
Barrel

ADJUSTABLE LIMIT GAUGES

A fixed gauge cannot be used for any check other than the dimension and tolerance for which it is made. In contrast, adjustable gauges have threaded contacts which can be adjusted to various limits of tolerance and wear.

1. Indicating gauges - which are also adjustable, include a direct reading device such as the dial indicator, to show the amount of variation from the specified dimension.

2. Dial Indicators - basic to measurement by comparison with the following features:

   a. Simplest indication is a lever which allows very small movements to be greatly enlarged.

   b. Range from low amplification test indicators in setup and in-process inspection, to highly precise electronic instruments.

   c. The amplification is the expansion of the gear train multiplied by the increase contributed by the pointer.

   d. All measurement requires movement.

   e. Direct measurement is static.

   f. Comparison measurement is dynamic.

The dial indicator consists of a graduated dial with an indicating hand; a contact point attached to a spindle, and an enclosed gear or lever amplifying movement. A short linear movement of the spindle is amplified by the internal mechanism and shows on the dial by a broad sweep of the indicating hand. An internal spring returns the spindle to its original position when pressure is removed. The spring provides the optimum measuring pressure without reliance of manual "feel."

The use of the dial indicator as a dynamic limit gauge is complicated and not generally used by entry-level workers until experience is gained in the more basic limit gauges.

STUDENT ACTIVITIES

1. Visit a manufacturing plant where large lots of hardware are received. Perhaps you may ask the tour director to illustrate the various limit gauges.

2. Ask the teacher if the metal shop uses limit gauges other than the feeler type gauges.

3. The entry-level employee in a manufacturing plant will become familiar with the many limit gauges through experience.

HISTORY AND BACKGROUND OF THREADS WHICH ARE IMPORTANT TO GAUGES

Screw threads and their standardization have proven to be one of the world's most difficult and costly problems. The British Screw System was devised in 1841 and was based on the inch measurement while the American industry was just starting. The American system was also based on the inch and was not developed until 1864. The development was brought about by the lack of standardization in the railroad development.

France and other countries used screw thread systems based on the metric system of measurement. World War I brought about a need for standards in screw thread systems, but it was not until World War II re-emphasized the problem that eventually the British, Canadians, and Americans agreed on the Unified Thread Standards.

A screw thread is a ridge of uniform section in the form of a helix generated on the external or internal surface of a cylinder or cone. Its purpose is to hold two components together.

ELEMENTS OF SCREW THREAD MEASUREMENT

1. Major Diameter - Largest diameter of a straight thread. (For a tapered thread, the largest diameter at any given plane normal to the axis.)

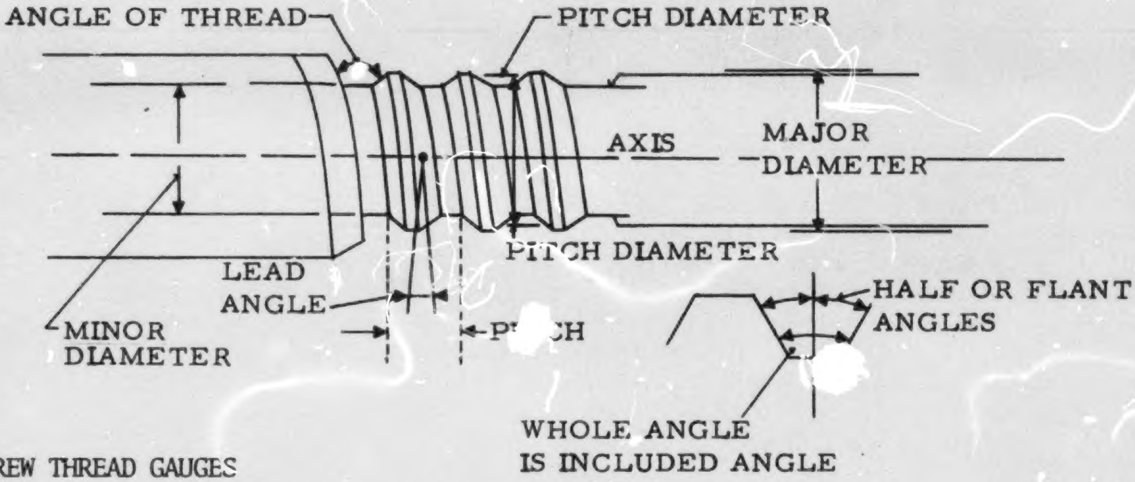
2. Minor Diameter - The smallest diameter of a single thread. (On a taper thread, the smallest diameter at any given plane normal to the axis.)

3. Pitch Diameter - Diameter of an imaginary cylinder, the surface of which would pass through the threads at points so as to make the width of the thread and the space between threads equal.

4. Angle of Thread - The angle included between the sides of the thread measured in the axial plane.

5. Lead (or Pitch of Thread) - The distance a screw thread advances axially in one complete turn.

   Single Thread - lead and pitch equal.
   Double Thread - lead is double the pitch.
   Triple Thread - lead is triple the pitch.



SCREW THREAD GAUGES

Thread gauges are usually classified into two groups:

Group I Working Gauges and Inspection Gauges (Used to check a product to maintain a tolerance as it is being machined and after completion.)

Group II Setting of Master Gauges (Used as standards against which the reference gauges are checked.)

Tha gauge tolerance accuracy is classed as follows:

Class W - Closest to which thread gauges are manufactured.
Class X - Average tolerance (largest percentage).
Class Y - Least accurate.

TEST AND INSPECTION FACTORS

The following are some of the test and inspection factors that are commonly considered in thread gauge checks:

1. Thread ring and plug gauges are commonly used for go/no-go inspections.

2. "Drunken" helix can be accurately checked optically.

3. Angle deviation of a gauge can also be checked optically by accurate alignment of a test point with a thread and microscope examination.

4. Thread comparators give direct indication of variation between production threads and a master setting gauge.

5. Optical comparators are used to check external threads. (With a master template, the inspector is able to observe the outside diameter, pitch diameter, form, thread angle, and lead error simultaneously.)

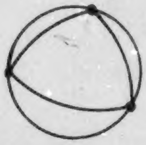
6. Minor diameters require special chisel-shaped anvils designed to engage only the minor diameter and not make contact along the flanks of the thread tooth.

7. The lead error in a thread can also be checked with a toolmaker's microscope.

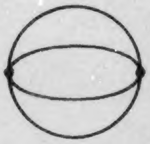
SCREW THREAD ELEMENTS OF DEVIATION (DO NOT HAVE TOLERANCES)

1. Out-of-roundness - limits thread engagement and allows for only line contact with the mating thread. Two types are:

Multi-lobe
3 Point

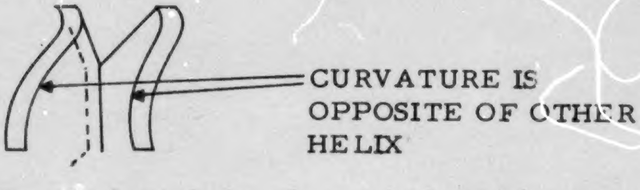


Oval
Point



a. Lead deviation
b. Flank angle deviation

2. Drunkenness - when the helix variation of a thread is a wavy deviation from the true helical advancement (advance of thread is irregular). An exaggerated sketch of this feature is:



NOTE: Number of threads per inch could vary.

3. Surface Defects - nicks or bruises on threads.

4. Taper - causes uneven torquing pressures.

TORQUE AND TORQUE MEASUREMENT

Associated with screw thread applications is the method of inserting screws and the corresponding control of the insertion. One of the major controls is torque.

Torque - The tendency of an application of force to produce rotation. (Measured in inch-grams, inch-ounces, inch-pounds, foot-pounds or corresponding metric units.) Basic techniques of torque measurement are:

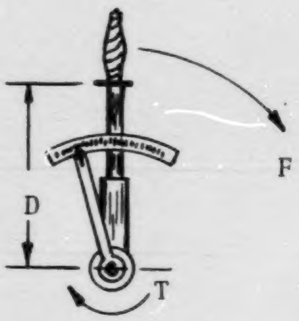
1. Static measurements of force at a fixed distance from the pivot point.
2. Dynamic or static measurements of a torsion produced in the shaft of a "prime mover" delivery torque to a load.
3. Dynamic or static measurements of the force and distance required to hold the housing of a torque generator or its load.
4. Measurement of the chain or belt tension required to rotate a pulley or load.

A gauging tool, torque wrench, is used to measure the resistance to turning. Features are:

1. Direct reading with mechanical or sensory options.
2. Very critical and must be closely controlled.
3. Equation is $T = F \times D$; where -

   T = Torque
   F = Applied Force
   D = Distance of lever arm

   NOTE: Lever length must be perpendicular to direction of applied force.



UDENT ACTIVITIES

1. Learn the basic features of screw-thread application in order to be prepared for future involvement.

2. Visit the metal shop and ask the teacher to demonstrate screw-thread applications and point out the major parts of the screw.

3. Ask the metal shop teacher to demonstrate the torque wrench and how it applies to screw-threads and associated criticality of insertion into various material.

PLANAR SURFACES

Planar surfaces are very important in the applications of inspection and quality control in the manufacturing industry. Accurate mechanical measurement would be practically impossible without the bases of these measurements. The two bases are surface plates and gauge blocks.

SURFACE PLATES

When discussing planar surfaces, flatness becomes a major consideration. Flatness, although considered basic, is a stranger to nature. The discovery of flatness, in reality, was a major breakthrough for the industrial revolution. It refers to the measure of deviation from a reference plane.

Surface plates are very relevant for two reasons:

1. They serve as a horizontal reference plane of sufficient strength and rigidity on which measurement operations may be supported.

2. Every linear measurement starts at a reference point and ends at a measured point.

APPLICATIONS OF THE SURFACE PLATE

1. The surface plate has many uses, some of them are:

   Grinding Table
   Planing Table
   Lathe Way

2. They are used to check the following:

   Fixed gauging (go/no-go)
   Scribing
   Comparative gauging
   Hold location
   Roundness
   Squareness
   Parallelism
   Angles

3. Tolerances of the surface plate per unit length can be up to .050 or 50 thousandths of an inch or more.

4 The materials, cleaning, care and use of surface plates:

a. Materials

Black Granite (most superior flatness)

- Closer tolerances and lower cost
- Non-corrosive and non-rusting
- Not subject to contact interference
- Non-magnetic
- Hard, stable, and long wearing
- Easy to clean
- Has thermal stability

Cast Iron and Steel

- Used mostly for separate reference surfaces
- Expensive
- Rusts and induce rust
- Must be oiled (oil collects dust causing error)
- Must be kept covered

b. Cost - depends on:

- Accuracy required
- Material used

c. Degradation of Workmanship

The plane surface can be developed to a high order of accuracy because there is no standard.

A product is not as precise as the machines. The machines are not as precise as the gauges, the gauges are not as precise as...

d. Applications

Use surface plates when setting up to check first article and/or when measurements/perpendicularity is in the 10 thousandths.

When comparing two articles.

When measuring one feature to another with no reference available on the part.

Apply degradation of workmanship principles to personal work and importance of care when working.

GAUGE BLOCKS

Gauge blocks are end standards that combine arithmetically to form combinations and are considered to be the keystone to measurement. Some of the important features of gauge blocks are:

1. They are the basic tool of precision measurement.
2. They allow greater precision than other instruments.
3. They must be considered when:

   Precision increases
   Length increases
   Importance of reliability increases
   Skill of the measure decreases

4. They are the most important metrological tool that will be encountered.
5. They are the most rugged and most delicate devices used.
6. They have a built-in (designed and produced) cushion of accuracy.

ENVIRONMENTAL AND THERMAL CONSIDERATIONS OF GAUGE BLOCKS

1. Must have environmentally controlled atmosphere for maximum accuracy.
2. Very stable, change little with age and care.
3. Very susceptible to corrosion due to moisture (should not breathe on or touch surfaces).
4. Must be cleaned and lubricated.
5. Will shrink if too much solvent is used (evaporation of solvent cools blocks).

RULES FOR GAUGE BLOCK CARE

1. Never attempt to wring or otherwise use gauge blocks that have been in contact with chips, dust, or dirt-laden cutting fluids.
2. Before using, clean blocks with a high-grade solvent or commercial gauge block cleaner. Wipe dry with a lint-free tissue.

3. Do not allow blocks to remain wrung together for long periods. Separate daily.

4. When not in use, place blocks in a safe place where they will not be damaged, preferrably in their case.

5. Before putting blocks away, clean the blocks and cover with a non-corrosive oil, or grease, or commercial preservative.

6. Be on constant guard for burrs. If anything has been placed on a block or if it does not wring readily, use a conditioning stone immediately.

7. Thoroughly clean gauge block case periodically.

PHYSICAL AND METROLOGICAL CONSIDERATIONS

Considerations that must be given to gauge blocks are two-fold, physical and metrological. They are:

Physical

Surface finish
Physical properties
Identification
Material:
  Alloy steel (most common)
  Carbide
  Stainless steel
  Chrome plate
Heat sensitive

Metrological

Measured plane
Reversible reference surfaces
Reference plane
(All reference surfaces are parallel to line of measurement)

GAUGE BLOCK GRADES

Grade AA - Laboratory grade
Grade A - Inspection grade
Grade B - Working grade
Grade AAA - The grand master for top level industrial calibration

TYPICAL SETS

The typical gauge block sets manufactured can be: rectangular, square, or cylindrical.

The sets are in groups of 121, 86, 56, 38, and 35. (With a set of 81 blocks, over 100,000 combinations are possible.)

The smallest size is 0.010 inches and the largest is 20.000 inches.

PRESENT INCH SETS (81 PIECE SET)

Inches	Series	Blocks	Sizes
0.039439 0.039755 0.000039	First	9	0.1001 through 0.1009 inches (increments of .0001)
0.039794 0.058661 0.000394	Second	49	0.101 through 0.001 inches (increments of .001)
0.0197 0.9646 0.0197	Third	19	0.050 through 0.950 inches (increments of .050 inches)
0.9842 0.9370 0.9843	Fourth	4	1.000 through 4.000 inches (increments of 1.0000 inches)

IMPORTANT FEATURES OF GAUGE BLOCKS

Wringing - Bringing two flat and smooth surfaces intimately together causing adherence (due to molecular attraction).

- Very important in the use of gauge blocks.

- Space between blocks can be reduced to a fraction of a mike (0.0001 inch) but 2 mikes are most common (90% of the time).

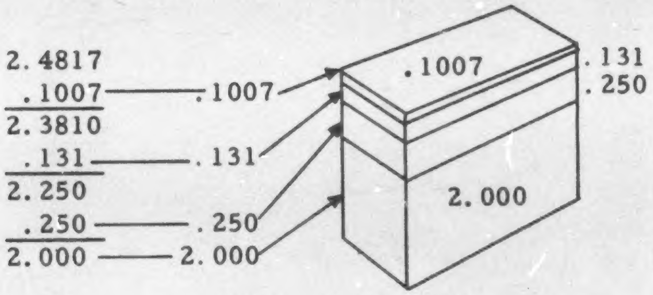
- Wringing interval is space between blocks, and is caused by:

  Poor surface finish (irregularities)
  Air films
  Oil films
  Grease films

Combining - Stacking various sized blocks to form a length dimension.

Example: Choose blocks to elimate figures from right to left (combination for the value of 1.605 is 1.605 - .105 - .500 - 1.000) = 0.

Example: For a value of 2.4817, the following combinations are made:



WHEN TO USE GAUGE BLOCKS (SLIDE-PRINCIPLE USES FOR GAUGE BLOCKS)

Calibration of other instruments and lesser standards.
Setting of comparators and indicator-type instruments.
Attribute gauging.
Machine set-up and precision assembly.
Layout.

HOW TO USE GAUGE BLOCKS FOR MEASUREMENT

Measurement by comparison.
Compare an unknown with a known quantity (standard).
Depends on:

1. Accuracy of standard.
2. Discrimination of standard.
3. Reading of instrument.

WEAR BLOCKS AND ACCESSORIES

Special carbide or steel blocks reserved for use as reference.

Used to minimize wear of blocks.

Surfaces at the ends of gauge block stacks.

Recommended when blocks are used for direct comparison.

Not needed when block holders are used.

Extends useful life of gauge block sets.

STUDENT ACTIVITIES

1. The student in high school is limited to availability of surface plates and gauge blocks. Therefore, study must be made by reviewing textbooks on the subjects and/or films that may be available that explain the usage.

2. Ask the metal shop teacher to arrange a plant visitation where surface plates and gauge blocks are used. Perhaps a demonstration of the usage of these planar surfaces will be possible.

3. The entry-level employee, although in most situations will not be required to use surface plates and gauge blocks, could observe more experienced employees when these basic tools are being used.

OPTICAL AND ANGULAR MEASUREMENT

OPTICAL MEASUREMENT

Optical gauging is by sight rather than feel or pressure. It is a field of study all by itself and will only be briefly described relative to the comparator and mechanical measurement.

OPERATING PRINCIPLES OF OPTICAL PROJECTORS (COMPARATORS)

1. Basic Elements Necessary:
    a. Light Source - Great intensity to produce a clear projection at high magnification.
    b. Collimating Lens - Refracts light into a beam with parallel rays of uniform intensity on the entire area of object (light condenser).
    c. Projection Lens System - Magnifies and transmits the object contour or image resulting from the parallel light rays (has six magnifications: 10, 20, 30-1/4, 50, 62-1/2, 100).
    d. The Viewing Screen - Where projected image of the object is displayed for inspection.
2. Produced on a Screen by:
    a. Projection - Shadow silhouette.
    b. Reflection - Mirror image of surface.
    c. Combination of projection and reflection.
3. Applications:
    a. Inspection by observation (cams, gears, crew threads, arcs and angles).

b. Inspect surface properties (texture, finish, flaws, scratches, and nicks).

c. Inspect contour (straightness, consistency of curvature, blending).

d. Inspect contact patterns - with mating parts.

4. Advantages:

Versatility
Speed
Simplicity
Accuracy
Reliability
Economy

5. Inspection by Comparison:

a. Screen Charts - Interchangeable with regular screen for inspection of standard forms (angles, radii, screw threads, gear forms).

b. Overlay Charts - Prepared for specific applications either as simple contour charts or charts with tolerance zones.

6. Inspection by Direct Measurement on Screen Image:

a. Linear Measurements (distance) - Using scales.
b. Angle Measurements - Using drafting protractors.
c. Radii - Using transparent templates.

7. Inspection with Measuring Devices Built Into Projector:

a. Coordinate Table Movements (X, Y Axis) - By reading the displacement distance on micrometer heads for linear dimensions.

b. Screen Protractors - Graduated screen rings combined with vernier for angle measurements.

8. Inspection with and of Fixturing and Special Attachments:

a. Helix Angle Adjustment - To project thread forms, normal to contour plane.

b. Transferring Dimensions - By means of work holding fixtures and charts with reference points.

c. Optical Sectioning - With special illumination.

9. Tool Maker's Microscope:

   a. Consists essentially of a high-powered microscope provided with a long travel calibrated mechanical stage and adequate illumination.

   b. Designed to satisfy varied measurement requirements such as resulting from the diverse tasks of tool making.

   c. A direct viewing instrument.

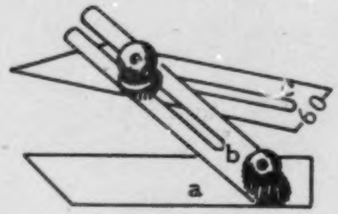
10. Applications:

    Linear measurements
    Coordinate and angular dimensions
    Contour forms (screw threads, circular arcs, etc.)
    Complex shapes (cams, gears)

ANGULAR MEASUREMENTS

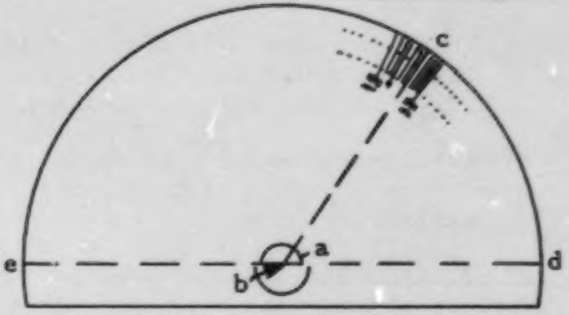
Not all measurements are of straight surfaces, which are parallel to a point of reference. There are measurements which have to be made of a slanted (oblique) surface. When a slanted surface has to be measured, some means of recording this measurement is required. The tools required are listed below. The angular measurements are given in degrees. The standard unit of measurement is based on the circle, which is 360° and the right angle which is 90°. Tolerance is necessary when working with all types of measurement. When working with angles, the tolerance can be given in minutes and seconds. The typical tolerance specified will be determined by the type of fit desired. An example of reading angular dimensions is as follows, 59° - 59' - 30". The angle is 59 degrees, ° being the symbol for degrees; 59 minutes, ' being the symbol for minutes; 30 seconds, " being the symbol for seconds.

COMBINATION BEVEL



This instrument is comprised of a stock (a) and a split blade (b), which form a bevel. The numbers 30°, 45° and 60° represent the angles the respective edges make with the adjacent sides. The tool can make direct measurement of a 30°, 45° and 60° angle, which can be transferred to the surface of the work.

PROTRACTOR



The protractor is semi-circular in shape. The divisions on the protractor are from 0° to 180°. The center pin enables you to set a straight-edge and measure the desired angle.

BEVEL PROTRACTOR

A bevel protractor combines the features of the protractor and combination bevel. The straight edges are attached to the protractor. This instrument allows measurement to be made by combining line and end measurements.

The combination bevel protractor has a variety of uses. The set enables use as a depth gauge, try and miter square, and locating center of a round piece of stock. The set consists of: a blade; square head; center head and a bevel protractor.

STUDENT ACTIVITIES

Activities for optical and angular measurements are limited except for the possibility of observation on a plant visitation that uses this type of equipment. Ask the teacher to arrange for a plant tour to become familiar with the equipment used and the skills required for these types of measurements.

ELECTRICAL MEASUREMENT

INTRODUCTION TO DC PARAMETERS

The use of electrical instruments and equipment to make measurements has become a major source of information and data in the complex manufacturing system as it is known today. Sophisticated techniques for electrical measurement were not introduced until the twentieth century, although the study of electrical phenomena dates back to the time of Benjamin Franklin and the American Revolution.

Measurement for electrical parameters is primarily the measurement of voltage, current, resistance, and frequency. However, most electrical measurements require only the measurement of current and voltage. The symbols for the basic electrical measurement parameters are:

I = Current where I =

E = Voltage E =

R = Resistance R =

F = Frequency

Diagrammatic symbolization of these basic parameters in direct and alternating current are:

Ⓘ and → = Current

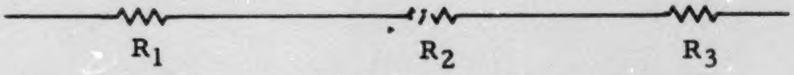
‖ = Voltage

/\/\/\ = Resistance

Voltage is the force that makes current move through the wires of a circuit. Current is the actual movement of electrons through a wire. Resistance is the force that controls the amount of current that can pass through a wire. Frequency in alternating current is the number of cycles occurring in each second of time.

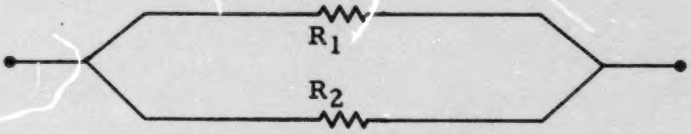
Both voltage and current can be measured with a simple electrical meter which uses magnetism and magnetic characteristics to measure the amount of current that flows. When a meter is connected to an electrical circuit, the flow of current through the coils of the meter creates a magnetic force. This magnetic force is used to move a needle. The amount of voltage, current, and resistance is shown by the position of the needle. The greater the current or voltage, the more the needle moves. To make the measurement easier, a scale is placed behind the needle to measure its movement. This scale is marked to show the value of current on voltage or resistance. The element the meter will measure is determined by the way the meter circuit is constructed and the way the meter is connected to the electrical circuit.

Where a meter is used to measure electrical values, a different circuit is required for each type of measurement. To determine the circuits used, a definition of series and parallel circuits must be made. Resistance in a series circuit is depicted as follows:



$$R_T = R_1 + R_2 + R_3$$

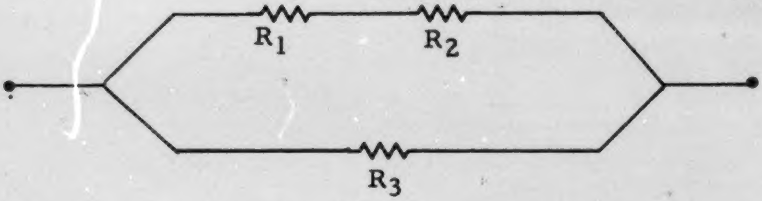
When two resistors are connected in parallel, they are illustrated as:



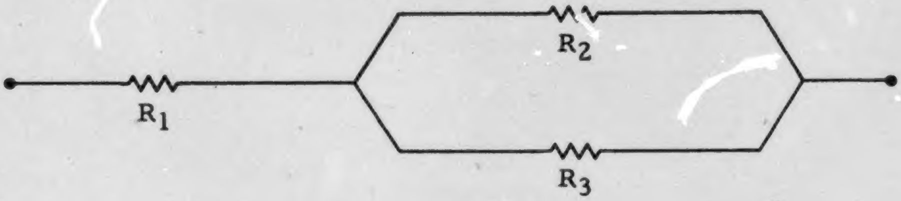
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

In a parallel circuit, if either resistor is disconnected, current can still flow through the other resistor. In a series circuit, if either resistor is disconnected, current flow stops because the circuit is broken.

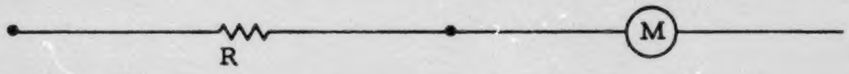
Most circuits have both series and parallel connections and they are called series-parallel circuits. The following figure shows two resistors in series and both in parallel with a third resistor.



The figure below depicts two resistors in parallel and the parallel resistors in series with a third resistor.

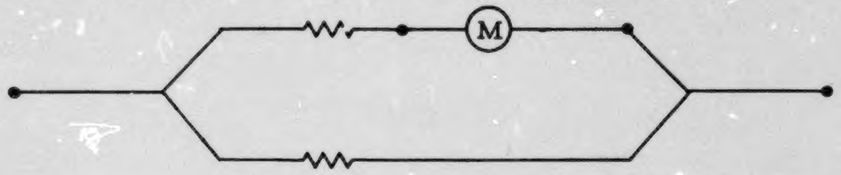


The coil in a meter has some resistance, but more resistance is usually needed. To measure voltage, a large resistance is placed in series with the meter coils as shown below:



For this circuit, the meter is called a voltmeter.

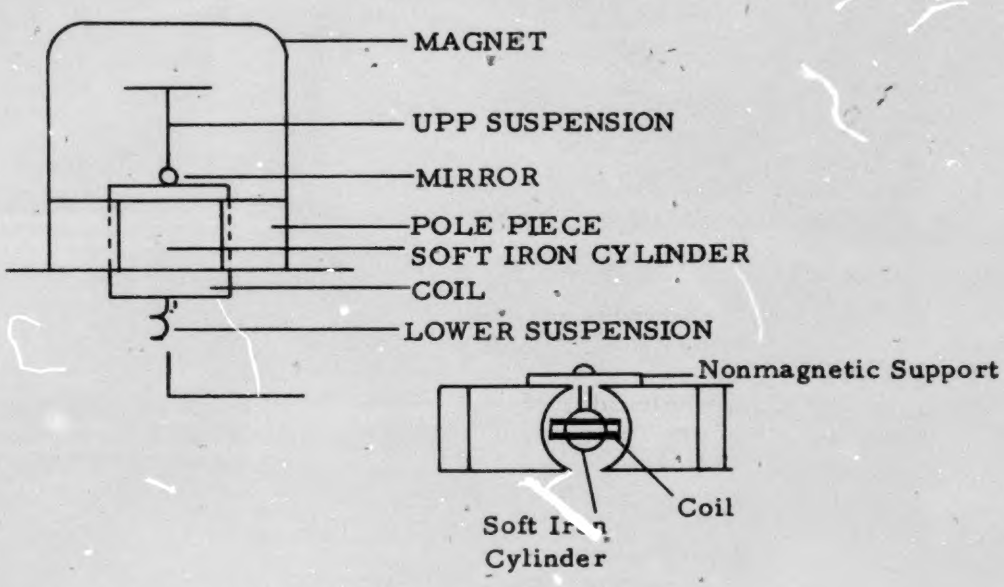
To measure current flow, a small resistance is placed in series with the meter coil and a second small resistor is placed in parallel with the meter and first resistor as shown below:



Meter connected as a voltmeter.

A simplified diagram of a D-C moving galvonometer is shown below:

D-C Moving-Coil Galvanometer.

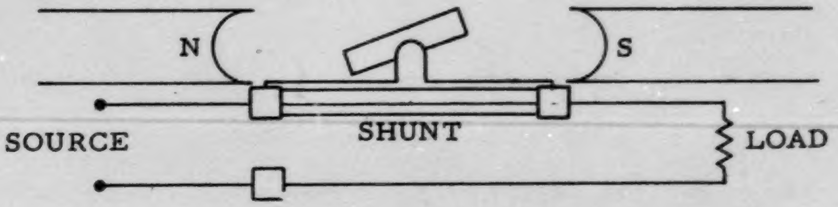


The galvonometer is a basic D'arsonval movement consisting of a stationary permanent magnet and a movable coil with attached mirror and pointer. The use of a pointer permits over-all simplicity in that the use of a light source and a system of mirrors is avoided. However, the use of a pointer introduces the problem of balance, especially if the pointer is long.

AMMETERS, VOLTMETERS, WATTMETERS, OHMMETER, AND OSCILLOSCOPE

Ammeter

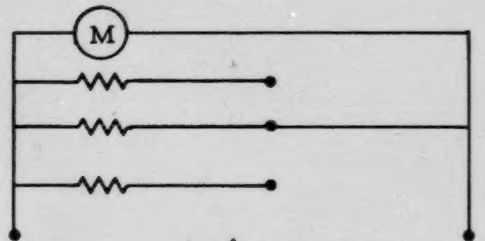
The basic D'arsonval movement may be used to indicate or measure only very small currents. A simplified diagram of an ammeter is shown below:



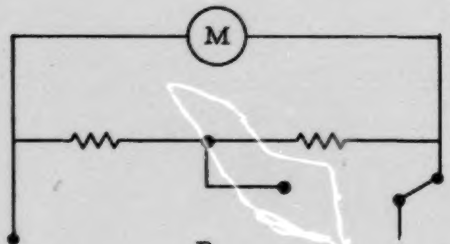
The resistance of the shunt is equal to the voltage drop for full-scale deflection divided by the rated current of the shunt.

Current measuring instruments must always be connected in series with a circuit and never in parallel.

Most ammeters indicate the magnitude of the current by being deflected from left to right. If the meter is connected with reversed polarity, it will be deflected backwards, and this action may damage the movement. The proper polarity should be observed in connecting the meter in the circuit. The meter should always be connected so that the electron flow will be into the negative terminal and out of the positive terminal. Common ammeter shunts are illustrated below:



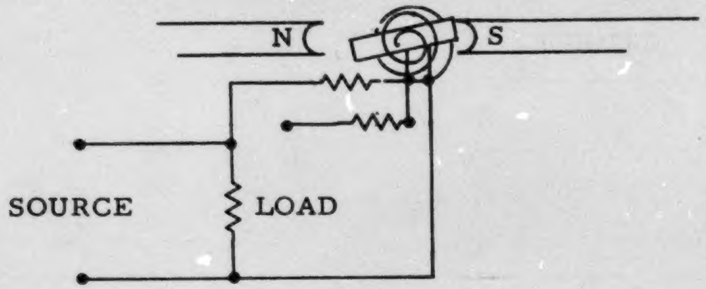
A



B

Voltmeter

The D'arsonval meter used as the basic meter for the ammeter may also be used to measure voltage if a high resistance is placed in series with the moving coil of the meter. A simplified voltmeter circuit is:



The value of the necessary series resistance is determined by the current required for full-scale deflection of the meter and by the range of voltage to be measured. As an example, assume that the basic meter is to be made into a voltmeter with a full-scale reading of 1 volt. The coil resistance of the basic meter is 100 ohms, and .0001 ampere causes full-scale deflection. The total resistance, R, of the meter coil and the series resistance is:

$$R = \frac{E}{I} = \frac{1}{.0001} = 10{,}000 \text{ Ohms}$$

and the series resistance alone is:

$$R = 10{,}000 - 100 = 9{,}900 \text{ Ohms.}$$

Voltage measuring instruments are connected across (in-parallel with) a circuit.

The function of a voltmeter is to indicate the potential difference between two points in a circuit.

Wattmeter

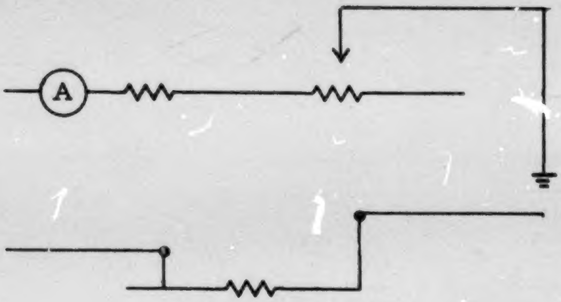
Electric power is measured by means of a wattmeter. Because electric power is the product of current and voltage,

$$P = I\,E.$$

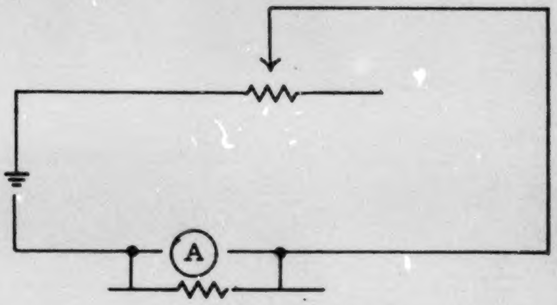
A wattmeter must have two elements, one for current and the other for voltage. For this reason, wattmeters are usually of the electrodynamometer type which multiplies the instantaneous current through the load by the instantaneous voltage across the load.

Ohmmeter

The series-type ohmmeter consists essentially of a sensitive milliammeter, a voltage source, and a fixed and a variable resistor all connected in series between the two terminals of the instrument. as shown below:



Series Ohmmeter



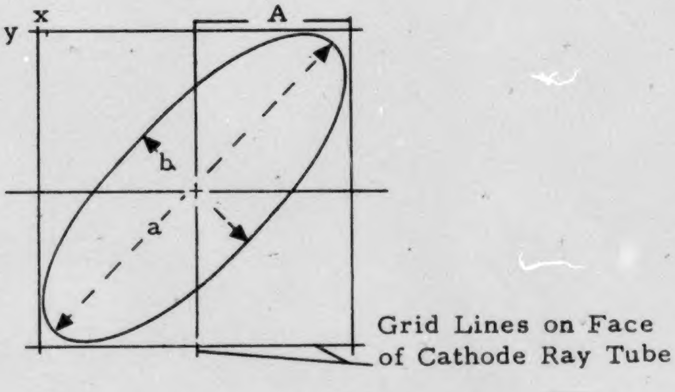
Shunt Ohmmeter

Before the unknown resistance is measured the test leads are shorted together and the variable resistance is adjusted for full-scale deflection. The point on the meter scale corresponding to full-scale deflection is marked "zero resistance."

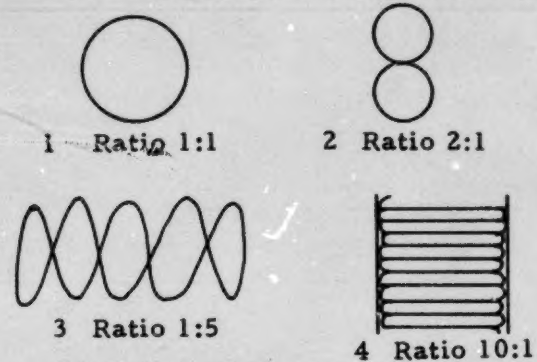
The Oscilloscope

Oscilloscopes are used to obtain information about current or voltage in an electrical circuit either to supplement the information given by indicating instruments or to replace the instruments where speed is inadequate. Oscilloscopes permit determination of current and voltage variations that take place very rapidly. These devices are frequently used to obtain qualitative information about a circuit such as current and voltage waves or time relationships between events in a circuit.

This form of measurement also allows determinations of frequency in the form of a graphical illustration. Some examples of the various forms that can be illustrated on an oscilloscope are:



Determination of phase difference of two sinusoidal voltages of same frequency by the pattern on the face of cathode-ray tube.



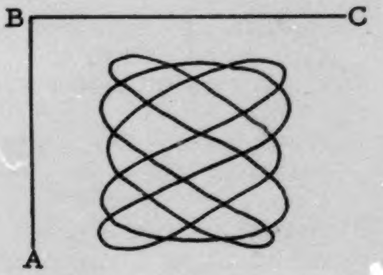
1 Ratio 1:1

2 Ratio 2:1

3 Ratio 1:5

4 Ratio 10:1

Lissajous Figures



Method of determining the ratio of frequencies in a Lissajous Figure.

Lissajous figures are patterns of voltages of different frequencies but related by a simple integral ratio as shown in the preceding figures.

AC VOLTAGE AND CURRENT

An alternating current (AC) consists of electrons that move first in one direction and then in another. The direction of flow changes periodically. Because most of the theory of electric power and communications deals with currents that surge back and forth in a certain manner known as sine-wave variation, the sine-wave is of considerable importance in alternating current. Symbols are:

I or → = Current

⏦ = Voltage

∧∧ = Resistance

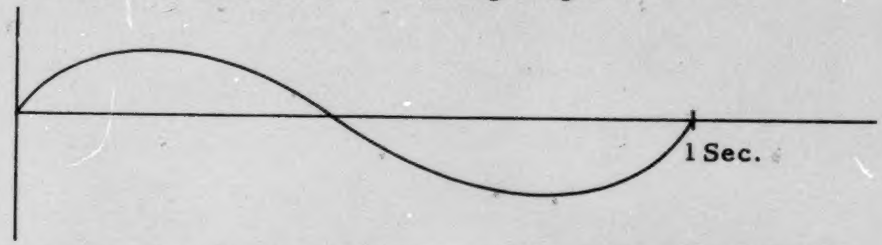
⊣ = Capacitance

ᴗᴗᴗ = Inductance

🅉 = Impedance

Important characteristics of alternating current are:

1. Cycle - As rotation of a generator continues, the two sides of the loop interchange positions and the generated voltage in each of them is the opposite direction. One complete revolution of the loop results in one cycle of induced AC voltage. This theory is illustrated as shown in the following diagram:



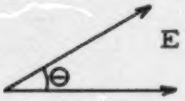
Points 0 to 1 represent one complete cycle of voltage in sine-wave form.

2. Frequency - The number of complete cycles occurring in each second of time. This is symbolized as "F".

3. Period - The time for one complete cycle of the generating force. This is illustrated as 1/f. (For example, the period of a 60-cycle voltage is 1/60 of a second.)

4. Phase Angle - The angle between vectors relative to the positions these vectors represent at any instant of time. This parameter is illustrated as angle Θ. One complete cycle of 360 electrical degrees is indicated in the equation:

$$e = E_\eta \sin\Theta$$

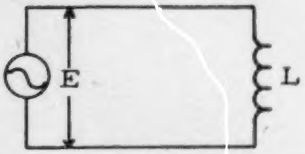


where e = instantaneous voltage
E_η = maximum voltage
Θ = the angle in electrical degrees representing the instantaneous position of the rotating vector. Therefore, when $\Theta = 60'$, $E_\eta = 100$ volts, $e = 100 \sin 60° = 86.6$ volts.

a. Inductance

Inductance is that property of a circuit that opposes any current change in the circuit. It is also the property whereby energy may be stored in a magnetic field. Therefore, a coil of wire possesses the property of inductance because a magnetic field is established around the coil when current flows in the coil. The relationship of inductance is illustrated by the symbol "L".

In a simple circuit, the relationship of inductance is shown as follows:

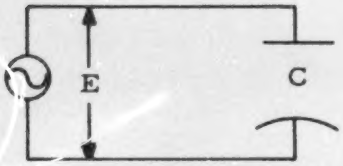


Where E is the applied voltage and L is the inductance.

b. Capacitance

Capacitance is that quality of a circuit that enables energy to be stored in the electric field. In simple form, it has been shown to consist of two parallel metal plates separated by an insulator, called a dielectric.

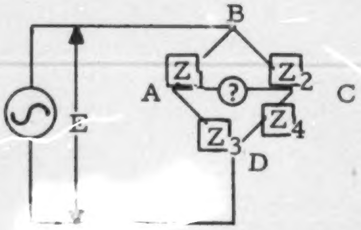
In a simple circuit, the relationship of capacitance is shown as follows:



Where E is the applied voltage and C is the capacitance.

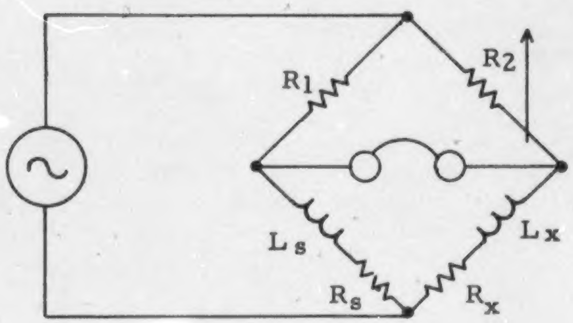
MEASUREMENT OF INDUCTANCE AND CAPACITANCE

Measurements of inductance and capacitance may be made conveniently and accurately by A-C bridge circuits. The simple form of the A-C bridge bears a strong resemblance to the wheatstone bridge. It consists of four arms, a power source furnishes alternating current of the desired frequency and suitable magnitude to the bridge. A four-arm bridge is illustrated in the following diagram:



Four arm A-C bridge (using Impedances Z_x).

An inductance comparison bridge is similar to form except that the bridge is made up of resistance and inductance relationships. An illustration is as follows:

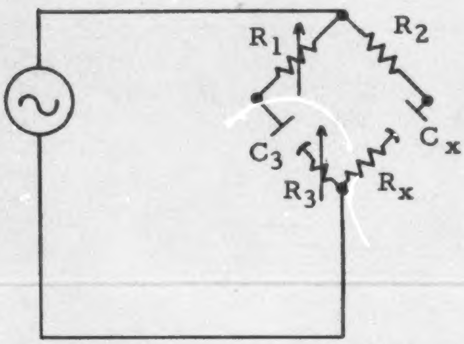


Inductance Comparison Bridge

In the inductance bridge, the relationship shows that the unknown inductance L_x is derived from the equation--

$$L_x = L_s \frac{R_2}{R_1}$$

A capacitance bridge relationship is used to determine an unknown capacitance by comparison to a known capacitance. The relationship is illustrated in the following diagram:



Capacitance Comparison Bridge

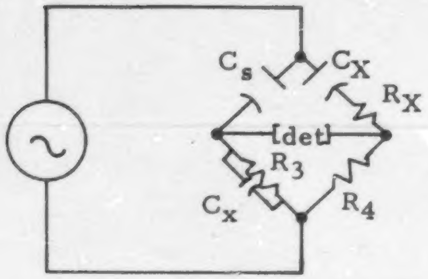
Other measurements of inductance and capacitance can be made by using the following bridges:

1. Maxwell Bridge - Permits measurement of inductance in terms of capacitance.

2. Hay Bridge - Differs from the Maxwell Bridge only in having a resistance in series with the standard capacitor, instead of in parallel with it.

3. Owen Bridge - Another circuit for measurement of inductance in terms of a standard capacitor. One arm consists of the standard capacitor only, and an adjacent arm contains a resistance and capacitance in series.

4. Schering Bridge - One of the most important A-C bridges. It is used to measure capacitance in general and in particular, is used to measure properties of insulators, condenser bushings, insulating oil, and other insulating materials. This bridge is illustrated diagrammatically since it is very important.



Schering bridge.

R_x = resistance in unknown Capacitor C_x
C_X = adjustable capacitor.
C_s = a high grade mica capacitor.
C_x = air capacitor

The equation is: $C_x = C_s \frac{R_3}{R_4}$

MEASUREMENT OF FREQUENCY

Several types of instruments have been devised to determine frequency. Some of them are: (refer to section on oscilloscope operation and use.)

1. Moving Iron Type - Has a moving element consisting of a soft-iron vane and two crossed stationary coils that are connected with some sort of frequency-discriminating network, so that one coil is stronger at low frequencies and the other at high frequencies.

2. Resonant Electrical Type - Two tuned circuits, one tuned to resonance slightly below the low end of the instrument scale, the other slightly above the high end. These two circuits may be combined with a crossed-coil instrument or an electro-dynamometer to make a frequency meter.

3. Mechanical Resonance Type - A series of reeds fastened to a common base that is flexibly mounted and that carries the armature of an electromagnet whose coil is energized from the A-C line whose frequency is to be measured.

4. Transducer Type - The frequency measuring function is entirely separated from the indicating instrument, which in this case is a simple D-C meter. Two parallel off-resonance circuits are used, one resonant below the instrument range and one above.

STUDENT ACTIVITIES

1. It is possible to make a simple meter to measure electricity. The materials needed to build a meter are as follows:

   a. One frozen concentrate juice container made of cardboard or a cardboard cylinder of about the same diameter.

   b. One 10 D (penny) nail or a piece of soft steel rod about three inches long and one eighth (1/8) inch diameter welding rod obtained from your teacher.

   c. Enameled wire approximately 28 gauge (American Wire Gauge) about 25 feet. Sources: Industrial Arts or Science teacher, the coil on the back of an old TV picture tube or a hobbie store. NOTE: Get the wire from an old TV, unwrap it carefully so that it does not break, kink, or knot up.

   d. One "D" cell battery or any flashlight battery with 1.5 volts (a 9-volt transistor radio battery will not work for this meter).

   e. Two 3 x 5 note cards.

   f. One small elastic or rubber band.

   g. One flash light bulb.

   h. Masking tape.

   i. Tools: scissors, file, pliers, hacksaw, ruler, and permanent magnet.

   The steps for the construction of the meter are as follows:

   Once the juice container has been washed out, measure two inches along the side of the container, from the open end, and cut this part off to make a cylinder two inches long. This will open the cylinder at both ends. Cut two "V" notches as shown in Figure 4(a), page 117.

   Now wrap the wire around the outside of the cylinder. To do this, begin about six inches from the end of the wire and tape the wire to the cylinder 1/8" below one of the "V" notches. Beginning at the notch, wrap the wires neatly around the cylinder each turn next to the other covering approximately one inch of the cylinder. At this point, begin another layer of wire and continue winding on top of the first. Wind this layer in the same direction as the first. Wind layer on layer until sixty-five turns have been made. When it is done, finish at the notch opposite one at which you started and tape the wire in place with a small tab of masking tape. Cut the wire leaving about six inches of lead, save the rest of the wire.

The pointer is made by cutting the head off of the nail. Then mark a point one-third the length from the end of the nail. File both sides of the nail for the two-thirds length until the nail balances at the mark [Figure 4(b), page 117].

Once this is finished, the short round end of the pointer must be magnetized. To do this, rub one pole of a permanent magnet in one direction over the short round end of the pointer until it is magnetized.

Cut a two-inch piece from the end of a note card. Fold this in half, parallel to the long side to make a "V" shape three inches long and one-inch on a side.

Push the pointer through the center of the card and fasten in place with the elastic, Figure 4(c), page 117. Position the pointer so that when the card is placed in the "V" notches of the cylinder, it balances and stands up straight.

Attach a 3 x 5 note card to the cylinder so that it is vertical and the pointer can move freely in front of the card. This is a place to mark your readings when you experiment with your meter, Figure 4(d), page 117.

Once the meter is made, you can take measurements. This meter will measure low value of DC (Direct Current) only. CAUTION - DO NOT MEASURE ANY ELECTRICITY OTHER THAN BATTERIES LABELED 1.5 V DC. These batteries are marked "D", "C", "A", "AA", "AAA", "AAAA".

Scrape the insulation off the ends of the wires from the meter coil. Connect each of the meter leads to one of the poles of a "D" cell battery. The meter pointer should move. The position in which it stops should indicate 1.5 volts. Note where this position is.

Clean the varnish insulation from the ends of the wire left over after you wound the meter coil. Connect one end of this to one of the meter leads. Now reconnect the battery with the long length of wire in the meter circuit. Does the meter pointer move as far this time?

Connect a flashlight bulb to the battery so that it lights. Touch the two leads of the meter to the contacts of the bulb. The movement of the pointer to a position on the scale shows the amount of voltage used to get the light to light.

Disconnect your meter and reconnect it so that one end of the battery is connected to the meter and the meter to the bulb, and then the other contact of the bulb to the battery (this is a series circuit). See Figure 5, page 118. The deflection of the meter needle is showing the current used by the light bulb.

The meter constructed is a device much the same as meters made and used in industry. Electrical properties measured are basic to the study and use of electricity. If more information is required on the subject, it is available from several sources.

Among the best sources for information is the nearest library, for both basic and advanced manuals and textbooks. Science teachers in high schools or colleges or graduate engineers, electricians, telephone repairmen, can also help. Many hobby shops and electric supply stores have a selection of basic manuals for sale which provide good background material and a number of experiments with electricity.

In order to build the circuits found in most of these books, a meter movement of greater sensitivity is needed. This can also be purchased at low cost from hobby or electrical supply houses. The meter constructed from this instruction is only a model to demonstrate how simple electricity is to measure.

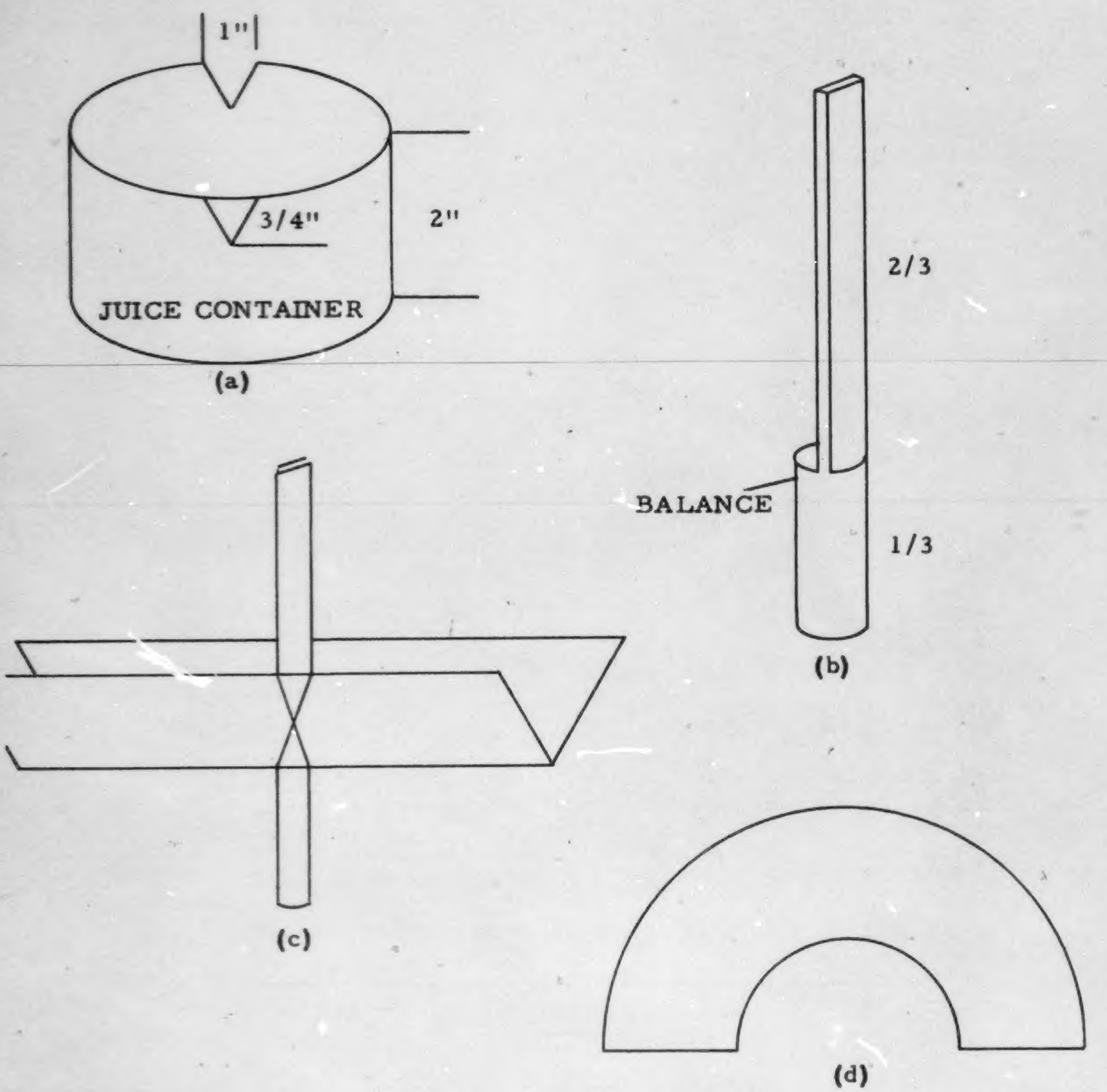
2. Visit the electrical laboratory in your school and ask the teacher to demonstrate basic electrical measurements on the meter available. Perhaps the teacher will allow you to practice making simple measurements under close supervision.

3. Arrange a plant visitation at a local electronic or electrical assembly plant. Ask the tour guide to demonstrate the different meters and how they are used in basic measurements.

4. Purchase a Heath Kit or similar meter brand name and assemble as directed. A basic ohmmeter or vacuum tube voltmeter would be a good starting point.

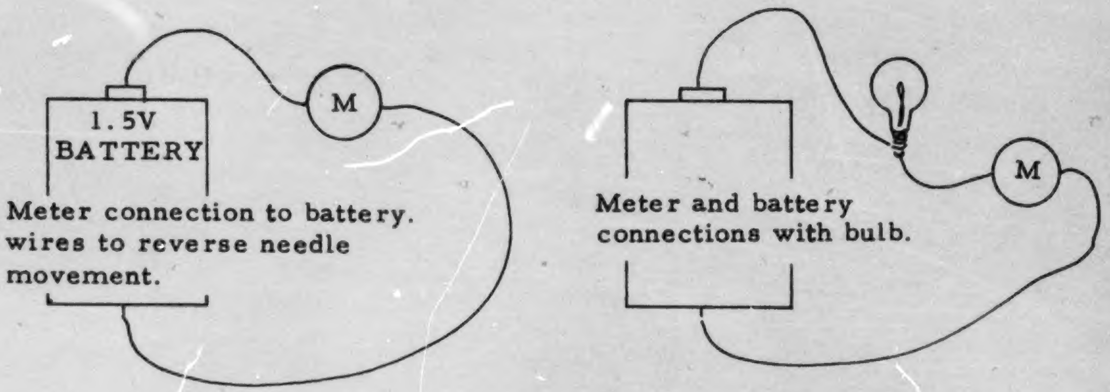
STEPS FOR CONSTRUCTION OF A METER

Figure 4



SERIES CIRCUIT

Figure 5


1.5V
BATTERY
M
Meter connection to battery. wires to reverse needle movement.
M
Meter and battery connections with bulb.

CHEMICAL MEASUREMENT

QUALITATIVE CHEMICAL TESTS

Chemical measurement is one of the major measurement categories of concern to Inspection and Quality Control. Some of the most common are reviewed in this section.

ACIDITY AND ALKALINITY

The degree of acidity or alkalinity (pH) of a solution or mixture is important to many situations. The concentration of hydrogen ions present in a solution is a function of the concentration of acid and degree of ionization. This definition applies equally to bases and by suitable consideration of the chemical equilibria involved to hydrolysis accompanied by ionization of a product which gives hydrogen or hydroxyl ions.

If an acid is present or added, the amount of hydrogen ion is increased and the amount of hydroxyl ion correspondingly reduced according to the laws of mass action.

$$\frac{C_H \times C_{OH}}{C_{H_2O}} = \frac{10^{-7} \times 10^{-7}}{1} = 10^{-14}$$

Where: C_H = Concentration of Hydrogen Ion
C_{OH} = Concentration of Hydroxyl Ion
C_{H_2O} = Concentration of Water

The value of C_H is commonly expressed as the pH value, which is the logarithmetic value, $\log_{10} 1/C_H$.

Measurement of pH values are commonly made of chemical processing solutions, effluents, soils, food stuffs, and other chemicals where acidity or alkalinity is important.

pH values may be determined by use of pH papers and the hydrogen electrode, antimony electrode, colorimetry, quin hydron electrode or glass electrode.

pH is measured in a scale starting at 7.0 ranging downwards towards 1.0 as being extremely acid and upward towards 13.0 as being extremely basic or alkaline. A pH of 7.0 means neutrality, that is the $C_H = C_{OH}$. Pure or distilled water approaches of pH of 7.0.

Sources of error in pH measurement include temperature of sample and standard, contamination of the test solution, degree of buffering required to reduce turbility caused by contaminants, degree of dissolved salts, type of colorimetric indicator used and calibration of electronic equipment used.

Typical areas of application include:

Metal cleaner solution control
Degreasing solution control
Household cleaner manufacture quality control
Soap purity quality control
Food preservatives purity control
Textile finishing materials quality control
Dye stuffs quality control
City water supply purity control

Halogens

The presence of halogens, chlorine, fluorine, bromine and iodine is important to many chemical reactions or processes. Methods of analysis include the following:

1. Silver nitrate is added to precipitate white curdy silver chloride from nitric acid solutions of soluble chlorides.

2. Silver bromide, pale yellow in color and silver iodine, yellow in color, are generally insoluble in ammonium, hydroxide solutions.

3. Silver bromide is slowly soluble and silver iodine hard to dissolve in ammonium hydroxide solutions.

4. Concentrated ammonium carbonate solutions dissolve silver chloride, whereas silver bromide is very slightly soluble and silver iodine insoluble.

Tests for presence of halogens require only commonly used laboratory equipment such as flasks, beakers, gram scales, distilled water, bunsen burner. Reagent grade chemicals must be used for test solutions.

Sources of error in precipitation methods such as used for detecting halogens include, unclean flasks or beakers, impure (not distilled) water, too low temperature of the test solutions, and interpretation of color indications.

Typical areas of application include:

Photographic emulsions quality control
Bleach manufacture quality control
Dye stuff manufacture quality control
Reagent grade chemicals purity control
City water supply purity control
Precious metal recovery control

NITROGEN COMPOUNDS

The presence of nitrogen compounds, sometimes referred to as combined nitrogen, is important to many chemical reactions and processes.

Methods of analysis include the following:

1. Ammonia is a nitrogen compound. Presence of ammonia gaseous solutions can [illegible] readily detected by its strong pungent odor. Another convenient test is to add eight

percent sodium hydroxide solution to the test solution and place moistened red litmus paper in the vapors and heat the mixture slowly. The litmus paper will turn blue in color if ammonia is present.

2. Nitrates contain ammonia. A convenient test for presence of nitrogen in an unknown solution is to combine one part unknown solution with ten parts concentrated sulfuric acid in a test tube. Then carefully add a saturated solution of ferrous sulfate by letting it flow down the tube wall. Do not mix solutions. Formation of a brown ring at the junction of the solutions indicates presence of nitrogen in nitrates. Nitrates are commonly used in fertilizers and explosives.

3. Amines contain ammonia. A convenient general test for presence of nitrogen in amines is to warm one milliliter of a test solution with two drops of chloroform and two milliliters of a strong alcoholic solution of potassium hydroxide. A very distinctive, strong, and disagreeable odor of carbylamine results if amines are present in the test solution. Standard laboratory apparatus is needed. Amines are commonly used as chemical reagents and are commonly found in nature in such things as fish oil and their derivatives.

SULFUR COMPOUNDS

The presence of sulfur compounds such as sulfates, sulfites, sulfides, and thiosulfate are important to many chemical reactions and processes.

Methods of analysis include the following:

1. Soluble sulfates may be identified by the barium sulfate precipitation method. Dissolve a test sample in water, make the solution acidic to litmus by adding 1:1 hydrochloric acid, heat to boiling, add a few drops of ten percent barium chloride solution and mix. Sulfate is indicated by a finely divided barium sulfate precipitate. Standard laboratory apparatus is needed. Soluble sulfates are commonly used as chemical reagents and are used in fertilizers and pharmaceuticals.

2. Insoluble sulfates must first be converted to soluble sulfates. For this purpose fuse a test sample with anhydrous sodium carbonate in a crucible. Let the melt cool and dissolve it in water. Filter to obtain a clean solution of soluble sulfate. Verify presence of soluble sulfate as described in the above paragraph.

METAL PROCESSING

The presence of metallic elements in minerals or ores is of primary interest in such processes as recovery of gold, silver, nickel, copper, iron, or tin. Identification of these metals in minerals or ores involves a series of tests in sequence whereby precipates are produced of the metals with various salts added to solutions of the mineral or ore.

The methods of test are many and only one example will be shown to explain the general approach.

1. Silver, mercury and lead commonly occur in the same ore or mineral. Fuse the sample with sodium carbonate, dissolve in water acidified with 1:3 hydrochloric acid, heat slowly, filter while hot and allow the filtrate to cool. Reserve the liquid for further testing. Lead is indicated if a fine white precipate developed. The residue on the filter is silver chloride or mercurous chloride or both. Wash with hot water and then 1:5 ammonium hydroxide solution. A black residue indicates presence of mercury. Acidify the ammonical solution with hydrochloric acid, a white precipitate indicates presence of silver.

2. Standard laboratory apparatus is used. Errors can readily occur in these tests if impure reagents are used or unclean apparatus is used. Careful prevention of contamination is necessary to ensure accurate results.

CONTAMINANTS

The presence of contaminants in public and industrial water supplies is an important matter requiring chemical analysis and control.

Some of the more common tests made are as follows:

1. Municipal water supplies are primarily checked for bacteriological content and activity. In addition, color, turbidity, dissolved solids, hardness, alkalinity, or acidity, iron, manganese, fluoride, free chlorine and pH are determined. Occasionally, a complete mineral content is determined.

2. Of these tests, color, turbidity and pH are qualitative in nature, i.e., exact numbers are not of concern. Color comparisons of a test sample are viewed under good illumination with water color standard solutions. Less or more color in the test sample indicates comparative amounts of the known chemicals in the color standard.

3. Turbidity comparisons are made in a similar manner as color comparisons. Water turbility standards contain known levels of minerals or other additives usually in a fine collodial state suspended in the water. Test samples are viewed under good illumination and compared for amount of turbidity present.

4. pH determinations were discussed earlier.

5. Errors in these tests primarily occur through unintentional contamination of test samples and to a lesser degree in judgement of color and/or turbidity levels or differences.

OTHER PROCESSES

The separation and identification of various cations by use of the paper chromatographic analysis method is an important quality control tool. Chromatographic techniques are capable of separating mixtures containing as many as fifty components with similar properties. This method gives strong proof if a certain cation is present or absent in a test solution.

The separation and identification of three cations will illustrate the method. The objective is to detect presence of silver, mercury, and lead in a nitrate solution suspected of containing these cations.

1. Modern laboratories employ very sophisticated and complex equipment such as the Gas Chromograph, the Spectrometer and the Electron Microscope to separate and identify chemicals in test materials and solutions. The principles and operation of these devices would be appropriate if their use is available.

2. Obtain three strips of regular laboratory filter paper six inches by one inch. One each strip draw a line with a pencil one inch from each end, place a dot in the center of one of the lines in each strip; and crease the strips along their lengths.

3. Place a drop of the nitrate solution on the pencil dot of each strip, allow to dry and place a second drop on the spots and allow to dry.

4. Fill three six-inch test tubes with one-half inch of distilled water, immerse the filter strips with the dot end down. Keep the tubes vertical and be careful to not splash the water. The water will then start to climb

the filter paper by capillary action. When the water rises to the upper line on the paper, remove the paper and allow to dry.

5. Immerse the strips one at a time in a six-inch test tube filled nearly to the top with potassium chromate solution. Remove them after two to three minutes and pass two of the strips one by one over 15 M NH_4OH vapors from a beaker in a hood. Observe the colors carefully, some mixing of colors may occur. Orange indicates lead present. Black indicates mercury. A spot of brick red on the third paper occurring after exposure to the potassium chromate solution indicates presence of silver. Exposure to the ammonia vapor will fade the brick red spot.

6. Comparative tests may be made to help in the color discrimination using individual solutions of lead, silver and mercurous nitrate.

STUDENT ACTIVITIES

Determination Of Approximate pH Value

Colometric Determination of pH Values

If the approximate value of the pH of a solution is unknown, the order of its magnitude must first be approximated in order to select the correct indicator for a more accurate evaluation. As a rule a few simple tests will supply this information. For example, if a solution remains colorless after a few drops of phenolphthalein are added, it indicates the pH is less than 8.0. If a second test is made with methyl orange and the solution assumes the color of the indicator (orange), it means the pH is greater than 4.5. Therefore, the solution has a pH value between 4.5 and 8.0. Additional tests using indicators with pH values between 4.5 and 8.0 can be used to establish a closer estimate of the true pH value. The following tabulation lists the various readily available indicators for this test method.

pH Indicators

	pH Range	Solvent	Acid	Alkaline
Thymol Blue	1.2-2.8	0.1% sol. in water	Red	Yellow
Methyl Yellow	2.9-4.0	"	Red	Yellow
Methyl Orange	3.1-4.4	"	Red	Orange
Bromophenal Blue	3.0-4.6	"	Yellow	Blue Violet
Bromocresol Green	3.8-5.4	"	Yellow	Blue
Methyl Red	4.4-6.2	"	Red	Yellow
Chlowphenal Red	4.8-6.4	"	Yellow	Red
Bromophenal Red	5.4-7.0	"	Yellow	Red
Bromothymol Blue	6.0-7.6	"	Yellow	Blue
Phenal Red	6.4-8.0	"	Yellow	Red
M Cresol Purple	7.4-9.0	"	Yellow	Purple
Thymol Blue	8.0-9.6	"	Yellow	Blue
Phenolphthalein	8.0-9.8	"	Colorless	Red

Solutions with pH value less than 7.0 are acidic and solutions with pH values greater than 7.0 are alkaline. Distilled water has a pH of 7.0.

Improving Estimate Of True pH Value

When the approximate value of pH is known, 3.5 or 10 cc (depending on amount of solution available) are measured out by means of a graduated cylinder and transferred into a Pyrex or other hard glass test tube. A measured amount of an indicator solution for some pH value between 4.5 and 8.0 is added carefully from a pipette of 1cc volume which is graduated in 0.01 cc. As a rule, 0.1 to 0.2 cc of a 0.1% indicator solution to 10 cc of liquid will be the proper amount. Then these buffer solutions (8 to 10 cc), the pH of which overlaps that of the unknown are taken and treated in exactly the same way. The following tabulation lists buffer solutions used for this test method.

STANDARD BUFFER SOLUTIONS

pH				
1.0	48.5 ml.	0.2 NHCL +	25 ml. 0.2 N KCl	dil. to 100 ml.
1.2	32.5 ml.	"	"	"
1.4	20.75 ml.	"	"	"
1.6	13.15 ml.	"	"	"
1.8	8.3 ml.	"	"	"
2.0	5.3 ml.	"	"	"
2.2	3.35 ml.	"	"	"
2.2	46.70 ml.	0.1 N HCl +	50 ml. 0.1M $KHC_8H_4O_4$	dil. to 100 ml.
2.4	39.60 ml.	"	"	"
2.6	32.95 ml.	"	"	"
2.8	26.42 ml.	"	"	"
3.0	20.32 ml.	"	"	"
3.2	14.70 ml.	"	"	"
3.4	9.90 ml.	"	"	"
3.6	5.97 ml.	"	"	"
3.8	2.63 ml.	"	"	"
4.0	0.40 ml.	0.1 N Na OH +	50 ml. 0.1 M $KHC_8H_4O_4$	dil. to 100 ml.
5.0	23.85 ml.	"	"	"
6.0	5.70 ml.	0.1 H Na OH +	50 ml. 0.1 M KH_2PO_4	dil. to 100 ml.
7.0	29.63 ml.	"	"	"
8.0	46.80 ml.	"	"	"
9.0	21.30 ml.	0.1 N Na OH +	50 ml. 0.1 M H_3BO_3	dil. to 100 ml.
10.0	43.90 ml.	"	"	"

Compare color of sample with the several tubes of buffer solution. The buffer solution which most closely matches the color of the sample provides a good second approximation of the sample solution pH value. A second improved approximation of the pH value may be made in a similar manner using another pH indicator lying between 4.5 and indicator used above, or between 8.0 and the same indicator, and a third improved approximation may then be made in a similar manner. This process may be repeated until all ranges of indicators and buffers have been used.

Chemical Measurement (Quantitative)

To prepare yourself in quantitative methods, activities are presented since they are considered necessary in skills development.

1. Exercise in the Use of the Balance.

   Discuss use of the balance in determination of weight relationship involved in chemical changes and analysis. Practice in weight measurement is important before attempting chemical analysis experiments. Measurement error probabilities and significances should be presented.

2. Separations of Solids and Liquids

   Many chemical analyses require separation of solids and liquids. Methods include formation of precipitates, gravity filtration, centrifuging and decantation. Practice in these methods are required. Use water solutions of silver chloride acidified with HCl, Borium Chloride acidified with sulfuric acid, and Aluminum Hydroxide reacted with Aluminum Nitrate. Use unknown composition samples and calculate weight units per volume using solid precipitates obtained.

3. Determination of the Percentage of Oxygen in Air.

   Since air is a mixture of gases, it is possible to expose a measured volume of air to a chemical subtance that removes (absorbs) the oxygen and leaves the other components unchanged. By measuring the decrease in volume occasioned by the removal of oxygen, it is possible to calculate percentage of oxygen in the original sample of air. A suggested method is to absorb oxygen from air in a mixture of three parts pyrogallic acid and 22 parts potassium hydroxide solution (measure parts by volume) and measure loss of air volume to determine percentage oxygen in the air. Standard laboratory equipment is required.

4. Determination of "Hardness" in Natural Waters

   Natural waters contain dissolved salts that cause the water "hardness." The degree of hardness relates to the "soap consuming power" of the water. The "harder" the water, the more it consumes soap. A hardness value for the water can be expressed in terms of the amount of soap consumed until a stable lather is produced. Mix a 100 ml. of water with a standard soap solution added in .5 ml. increments and agitate vigorously each time. Continue additions until a stable lather is obtained. Divide the number of milliliters of soap required by 100 to obtain a "hardness value" of the water.

5. The Ammonia Content of a "Household Ammonia"

A typical quantitative chemical analysis measurement used for quality control of the manufactured product. Household ammonia is prepared by passing ammonia gas (NH_3) into water. Ordinarily, one volume of water dissolves about 800 volumes of NH_3. Ammonia reacts with water (H_2O) to form NH_4OH, ammonia hydroxide. The law requires Household ammonia sold in stores contain not less than 9.5 percent NH_3. Weight and titrate an ammonia solution sample with 3.g of HCl per ml. solution, use methyl red indicator. When the end point is reached, calculate the percent ammonia (NH_3) from the weight of HCl in the standard solution used divided by the weight of the ammonia sample.

$$\% NH_3 = \frac{\text{Mil of HCl Used x .3 gm/mil}}{\text{Grams of Ammonia Solution Tested}} \quad x \quad 100$$

Repeat test five times and calculate the upper control limit (UCL) and lower control limit (LCL) as follows:

$$\bar{R} = \frac{\text{Highest Reading} - \text{Lowest Reading}}{5}$$

$UCL = D_4\bar{R}$ Where: $D_4 = 2.114$ for sample size 5

Central Line $= \bar{R}$ $D_3 = 0$ for sample size 5

$LCL = D_3\bar{R}$

A control chart could then be initiated and used to check future production lot quality. The range of 5 samples taken at a later date would not exceed the $UCL = D_4R$ as long as the process producing the ammonia solution remained unchanged.

6. The Acid Content of Vinegar for Household Use.

This must not be less than four percent weight expressed as acetic acid. Vinegar is a rather complex mixture that is produced by fermentation of apple cider, corn sugar, or grape juice. The principal chemical changes involved are formation of ethyl alcohol (C_2H_5OH) and the oxidation of the alcohol to acetic acid ($HC_2H_3O_2$) by "Bacterium acetic" and related organisms. Acid content is determined by titration samples with standard sodium hydroxide solution.

The procedure is quite simple and easily accomplished with normal laboratory equipment.

Wash a burette thoroughly with distilled water. Fill it exactly to the zero mark with a 0.1 gm NaOH per mil. solution. Weigh a clean dry 250 ml. beaker to the nearest 0.1 gm. Add 20 ml. of vinegar. Weigh filled beaker to nearest 0.1 gm. to determine weight of vinegar. Add 20 ml. of distilled water and two drops of phenolphthalein indicator solution.

Titrate the sample of vinegar with the standard sodium hydroxide from the burette. The first appearances of a permanent pink coloration denotes the end-point in titration. Record the initial and final burette readings and calculate the percent acid as follows:

Weight of beaker ______________gm.
Weight of beaker + sample ______________gm.
Weight of sample (2-1) ______________gm.
Initial burette reading ______________ml.
Final burette reading ______________ml.
Volume of NaOH solution used ______________ml.
Conc. of NaOH solution used ______________gm./ml.
Weight of NaOH in the volume of NaOH solution used ______________gm.
Weight of $HC_2H_3O_2$ neutralized by weight of NaOH ______________gm.
Percent of acid found (9 divided by 8) ______________%

Control charts for range R and upper and lower control limits may be prepared in a similar manner as described above for percent of NH_3 in "household ammonia."

7. Chemical Analyses of Food Products

These are vital to control quality and safeguard the consumer's health. To illustrate the kinds of tests made, those performed in tomato paste are outlined below: (Test method details are not presented in this outline. Instructors are referred to such references as the "International Chemical Series - Technical Methods of Analysis," by Griffin, McGraw-Hill Company.)

a. Total Solids - Evaporate to dryness and weigh.

b. Insoluble Solids - Dilute, centrifuge, dry and weigh residue.

c. Soluble Solids - Subtract percentage of insoluble solids from total solids to obtain percentage of soluble solids.

d. Sand - mix sample with water, let stand 5 minutes, decant off supernatant liquid into second beaker, let stand 5 minutes, decant into a third beaker. Repeat starting with first beaker, fill with water, mix, let stand 5 minutes, decant into the second beaker and so on. Finally, decant all supernatant from the third beaker and discard. Dry, ignite and weigh residue in third beaker to obtain amount of sand.

e. Sodium Chloride - Determine Chlorine volmetrically by the Volhorant method using nitric acid solution of the ash obtained by igniting a 10 gm. sample in a crucible. Calculate percentage of NaCl using
$NaCl = AgCl \times 0.4078$
1cc).1 N $AgNO_3$ = 0.005845 gm. NaCl.

f. Other tests made include reducing sugars, sucrose, total acids, volatile acids, butyric acid and fixed acids.

CC 010 358